INTERIM REPORT ON RESEARCH

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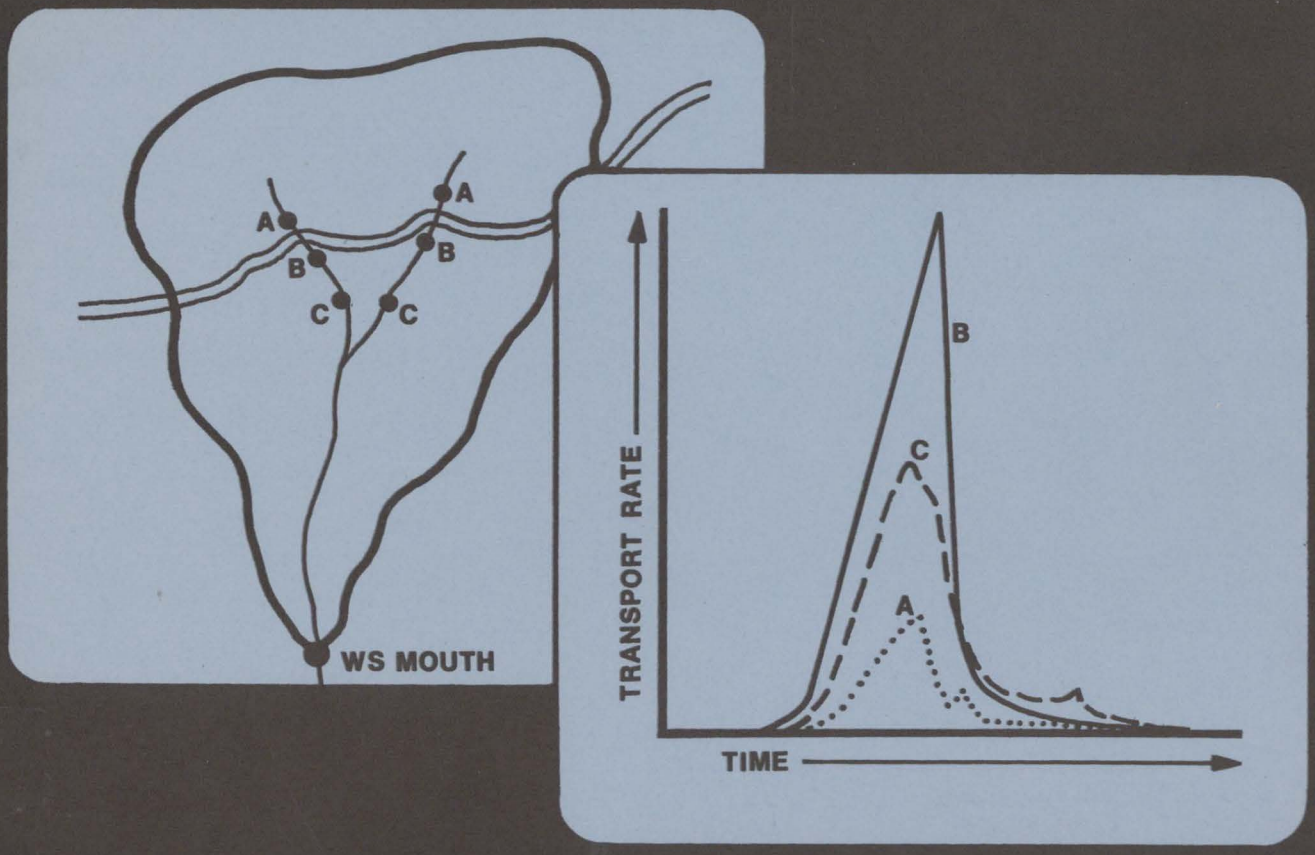
HORSE CREEK ADMINISTRATIVE-RESEARCH PROJECT

--A cooperative effort of the Northern Region and the Intermountain Forest and Range Experiment Station



FEBRUARY, 1981

USDA FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

INTERIM REPORT

ON

RESEARCH

HORSE CREEK ADMINISTRATIVE-RESEARCH PROJECT

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The Horse Creek Administrative-Research Study has been active since 1965. From its initiation until 1978 was a period of instrumentation and collection of hydrometeorological data for undisturbed conditions. In 1978 and 1979 roads were constructed across the south aspect slopes in the Main Fork of Horse Creek and clearcut harvesting will begin on these same slopes in 1981. Harvesting on the north aspect slopes in the Main Fork drainage will commence in 1985.

Many changes have occurred since this research project began in 1965. The evolution of this project has seen changes in personnel, funding levels and sources, and project objectives. A brief discussion of the history of this project will provide a better understanding of the magnitude of the project, the types and amounts of data being collected, and the basic objectives of the study.

Harold Haupt, INT research hydrologist, in conjunction with the Nezperce National Forest, was interested in quantifying the desynchronization of stream discharge during the snowmelt season as a result of harvesting on south and north aspect watersheds. His hypothesis was, simply stated, that silvicultural treatments to initiate early snowmelt on south aspects and to delay snowmelt on north aspects, should broaden the snowmelt hydrograph for the Main Fork of Horse Creek without increasing peak stream discharge or the duration of high stream discharge.

In the early 1970's, Region 1 hydrologists were developing a set of cutting guidelines which would constrain the amount of harvesting in a 3rd to 5th order watersheds based, in part, on channel stability. They hypothesized that increases in the duration of high stream discharges or peak discharges following harvesting could cause detrimental channel alterations, i.e., channel degradation. The threshold of increased streamflow, above which damage may occur, was a function of the stability of the channel. It was decided that the Horse Creek watersheds were an ideal place to determine the streamflow response to various percentages of stand removal and the channel response to the increases in streamflow. Thus, nine south aspect watersheds will have different percentages of their area in a clearcut condition, ranging from 15.7 to 52.4%. The subsequent results will be used to validate and/or improve the predictive capabilities of the Region 1 cutting guidelines.

During the 1970's, water quality problems, especially sedimentation, as it relates to forest practices, became a greater concern to the public and to land managers. Once again, Horse Creek was considered an ideal place to evaluate water quality responses to forest management practices. This resulted in the incorporation of different harvesting systems on the south aspect watersheds, including helicopter, skyline, and ground skidding methods. Future studies will evaluate differences in erosion, stream sedimentation, and stream chemistry resulting from the different harvesting systems.

The other management activity to be evaluated was road construction. Roads are often the major source of sediment to streams in management impacted watersheds. Thus, the roads needed for timber harvest and removal will be evaluated as to their relative impact on streams as compared to the harvesting operation. To do this, harvesting on the south aspect watersheds will be delayed until two years after road construction.

The Region 1 engineers supported the road study in Horse Creek. Through their concerns and funding, new objectives were added to the Horse Creek project. Briefly the road study will determine the effects of roads on water quantity and quality and will quantify: differences between alternative road standards, the contributions of sediment from various portions of the road prism, downstream sediment transport and storage, impacts on aquatic ecosystems, performance of specific design features and treatments, and the cost effectiveness of alternative road design and treatment practices. Additionally, there are objectives that are not directly related to water quality and quantity. Evaluations are being made of the esthetic impacts of the different road standards and investigations are being made on the relationship between subgrade moisture content and road surface stability.

The purpose of this report is to present a summary of results from completed studies in the Horse Creek Watersheds and to present the status of ongoing projects. Status reports will include data summaries and results, where applicable.

SECTION 2

STUDY SITE DESCRIPTION

BACKGROUND

The Horse Creek Administrative-Research Project was initiated in 1965 as an integral part of the Meadow Creek Barometer Watershed. It is part of a large Forest Service network of watersheds across the nation where administrative activities are directed toward the collection of hydrometeorological data to determine the impact of various management activities on the soil and water resource. Criteria for selection of a watershed representative of each major hydrologic zone in the country were: 1) drainages were to be undeveloped; 2) 40,000 acres in size or larger; 3) located in areas where quality and timing of surface flow was important; and 4) to have a variety of conditions and uses. The 243 square mile Meadow Creek Drainage was selected as the Barometer Watershed representative of the Northern Rocky Mountain Physiographic Province.

The 7,730 acre Horse Creek Watershed was selected as an area within the Meadow Creek Watershed for intensive study. The Horse Creek Project was initially a joint endeavor between Region 1 - Nezperce National Forest and the Watershed Management Research Work Unit, Intermountain Forest and Range Experiment Station. The objective of the project was "to assess the effects of a timber sale and road construction project incorporating alternative logging and road systems, by installing a network of instruments to monitor hydrologic parameters before, during, and after management activity, assessing impacts on the soil and water resource." (USDA 1976).

Area Description

The Horse Creek Watershed is located in Township 30 North and Ranges 8 and 9, Boise Meridian, in northcentral Idaho. The study area consists of 7730 acres on the Nezperce National Forest, approximately 35 air miles east of Grangeville, Idaho (Fig.1). Horse Creek flows eastwardly into Meadow Creek four miles above its confluence with the Selway River.

The Horse Creek study area is comprised of two major watersheds drained by the East Fork and Main Fork of Horse Creek (Fig. 2). The East Fork Watershed is a control watershed which will remain in its present undisturbed state. The Main Fork Watershed has received various management activities. The East Fork and Main Fork Watersheds drain 3561 and 4169 acres, respectively.

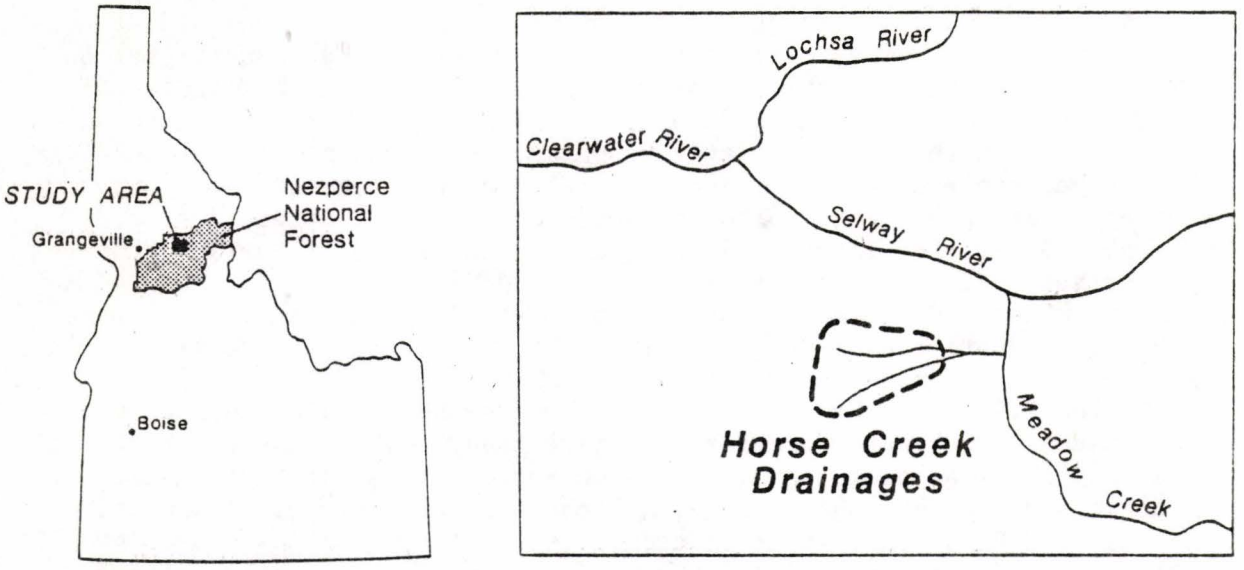

Figure 1. Location map for the Horse Creek Administrative Research Study Area.

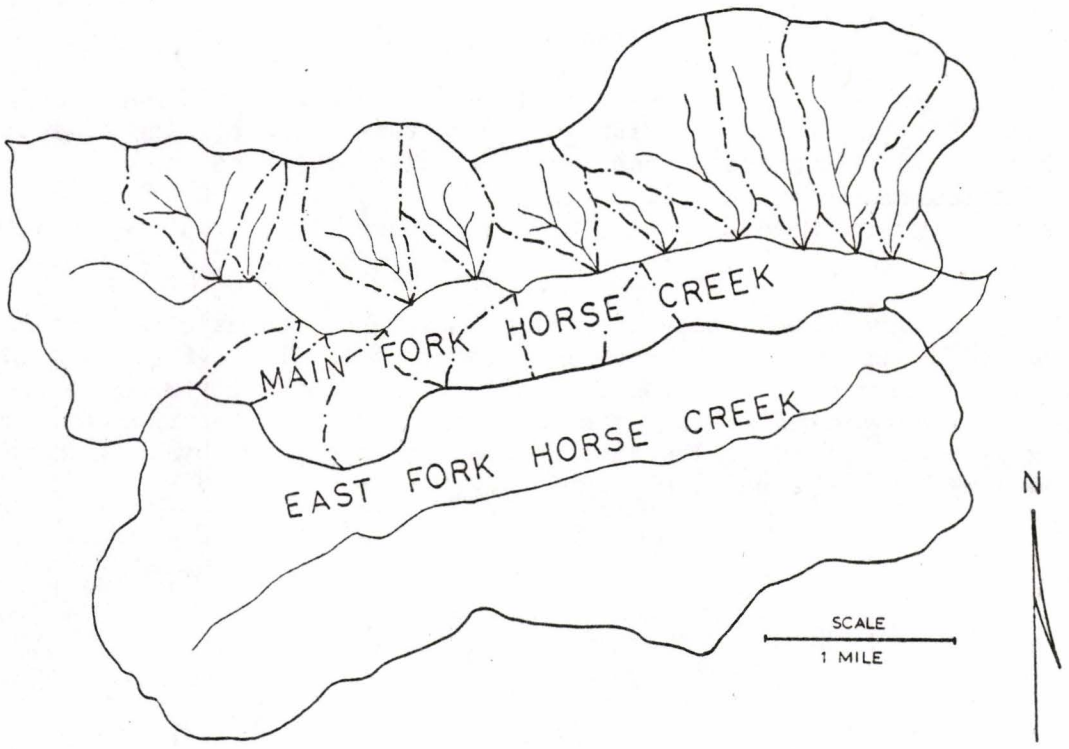

Figure 2. Map of the main and east fork drainages of Horse Creek

PHYSIOGRAPHY

The Horse Creek Watersheds are a part of the Selway Moderately Dissected Lands Subsection (Arnold 1975). This land class is a highly dissected portion of an old erosion surface. However, Hughes (1965) states that the eastern three-fourths of the Horse Creek Watershed is more youthful, exhibiting lower drainage densities and steeper stream gradients. Streams in this watershed have not reached a graded condition even those underlain by the old erosional surface. Channel downcutting and extension are dominant processes in these streams.

The East Fork and Main Fork of Horse Creek drain eastwardly. Elevations range from 6025 feet at the southern divide of the East Fork Watershed to 4060 feet at the confluence. The mean elevations for the Main Fork and East Fork Watersheds have convex side slopes that often exceed 65 percent on the lower slopes. Slopes tend to be more gentle on the upper side slopes and near the head of the watersheds. Median side slopes for the Main Fork and East Fork Watersheds are 31 and 36 percent, respectively. The Main Fork has 30 percent more area with a southern aspect than a northern aspect, while the East Fork has 62 percent more area with northern than than southern aspect.

Landtypes have been mapped for the entire study area by Richard Cline, soil scientist, Nezperce National Forest. The lower slopes of the Horse Creek study area along the Main Fork and East Fork and most of the ridge between them consist of early to mid-stage stream breaklands. These landforms occur on sides of deeply incised V-shaped valleys and typically have slopes in excess of 60 percent. Lateral stream incisement is well defined and slopes are distributed laterally. The streams, including Horse Creek, adjoining these landtypes generally do not approach grade near their mouths.

The upper slopes of Horse Creek are generally early and mid-mature pluvial landforms. These landforms are typically narrow ridgetops or hills of moderate relief. Depositional material makes up less than half the surface material and the drainage pattern is dendritic. Moderately frost churned landforms are found along the ridges in Horse Creek.

GEOLOGY

These watersheds are located on the border of the Idaho Batholith, a large igneous intrusion in central Idaho and Western Montana. Within the Batholith are pendant masses of metamorphosed sediment of schists, gneisses, and quartzites. These border zone rocks are part of the Belt Super Group (Bennett 1974) composed of sedimentary and metasedimentary rock of primarily gneissic material (Greenwood and Morrison 1967). This gneissic rock contains large proportions of quartz, plagioclase, biotite, and muscovite (Hughes 1965).

During 1978 a minerals inventory was made of the Horse Creek study area. It was determined that there were no significant mineral deposits

in the area. Subsequently the project area was withdrawn from potential mineral exploration and development to protect the continuity of the projects.

SOIL

A basic soil survey was performed in Horse Creek in 1965. The delineations of soil types were made from aerial photos followed by field checking of homogeneity morphology. The soils found were of the Jughandle, Lochsa, and Suttler series (Alvis 1965).

The deeply weathered gneissic regolith is sandy but with a substantial proportion of silts and clays. Alvis (1965) found the most commonly occurring soil type on the north slopes of the Main Fork Watershed was a moderately deep, well drained, sandy loam to loam, tentatively classified as the Jughandle series. The thick surface layers of this soil contain much loessal silt.

The other soil type common to these subwatersheds is a moderately shallow, well drained, loam to sandy loam. These soils are found on the steep slopes in the lower portions of the subwatersheds. The potential for surface erosion on this soil type is high.

VEGETATION

The Horse Creek drainage is timber covered with the exception of some wet bottom land along stream channels and some meadows and alder glades along the upper drainage boundary. The dominant habitat type is Thuja licata/Clintonia uniflora. Other habitat types represented are Abies lasio carpa/Xerophyllum tenax, Abies lasiocarpa/Clintonia uniflora, Abies grandis/Xerophyllum tenas, and Abies lasiocarpa/Menziesii ferruginea. Tree species found in significant numbers include: grand fir (Abies grandis), western red cedar (Thuja plicata), western larch (Larix occidentalis), Engelmann spruce (Picea engelmannii), and lodgepole pine (Pinus contorta). Douglas-fir (Pseudotsuga menziesii) and ponderosa pine (Pinus ponderosa) are predominant on south facing clopes. In general, the overstory vegetation is overmature and decadent. Damage is heavy from western spruce budworm (Choristoneura occidentalis) and Indian Paintfungus (Eichin odontium tinctorium).

Understory species include thin leaved huckleberry (Vacciuium membranaceum), pacific yew (Taxus brevifolia), mountain alder (Alnum sinuata), Menziesia (Menziesia ferruginea), bear grass (Xerophyllum tenax), and several forbs representative of the Pachistima union. Wildfire has not played a major role in stand composition for at least the past 150 years.

A Stage II survey of the south aspect portion of the Main Fork drainage indicates that average overstory volume is about 28,000 bd. ft./acre and Abies grandis is the dominant species. Average basal area is 150 sq. ft./acre and the site index varies from 70 to 80.

WILDLIFE

Shiras moose, Elk, white-tailed deer, mule deer, black bear, and cougar are the big game animals inhabiting Horse Creek. Because of the high elevation, Horse Creek is not important for elk winter range. Summer and fall use by elk and deer is heavy, however, and can be attributed largely to the area's solitude and to the mountain meadows and natural openings along the divides surrounding Horse Creek. Moose inhabit the area all year and the Pacific yew stands make Horse Creek an important moose winter range. There are several smaller mammals which inhabit the area including the coyote, bobcat, porcupine, snowshoe hare, and various species of rodents, marten, mink, and weasel. The pine marten is the only rare animal inhabiting Horse Creek.

The presence of large boulders and falls in Horse Creek just above the mouth creates a natural barrier to migratory fish. Rainbow trout up to ten inches in size have been observed in both forks of Horse Creek and have been determined to be of west coast hatchery stock introduced at an unknown time. Meadow Creek is an important stream for andromous fisheries and sediment produced in Horse Creek may have an influence on these fisheries.

CLIMATE

The Horse Creek Watersheds are affected by modified marine air masses from the Pacific Ocean. The summers are warm and relatively dry and the winters are cold and wet. Only the climatic data at Buck Meadows and Lower Horse Creek have been used for characterizing the climate of Horse Creek. Buck Meadows is near the upper end of the Main Fork and Lower Horse Creek is near the confluence of the East and Main Forks. These two stations give a good indication of the variation of temperature and precipitation along the Main Fork of Horse Creek.

The spacial and annual variation in precipitation is pronounced. The 12-year, 1966-1977 average annual precipitation at Buck Meadows is 42.2 inches, ranging from 26.1 to 52.8 inches (table 1). The average annual precipitation at Lower Horse Creek is 39.9 inches. At both sites the maximum precipitation occurs in January and the minimum in August. Summer rain events are characterized as convective storms of high intensity and relatively short duration.

Table 1. Average monthly precipitation in inches and as percent of annual total for Lower Horse and Buck Meadows climatic stations, water years 1966-1975.

Station	Annual Precipitation	Monthly Precipitation											
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Lower Horse (elev. 4,160')	inches 39.9	2.8	3.6	5.1	7.2	3.5	4.2	3.5	2.5	3.4	1.0	0.8	2.3
	%	7.0	9.0	12.8	18.0	8.8	10.5	8.8	6.3	8.5	2.5	2.0	5.7
Buck Meadows (elev. 5,600')	inches 49.0	3.0	4.4	6.8	8.9	4.7	4.7	4.7	3.3	3.8	1.1	1.0	2.6
	%	6.1	9.0	13.9	18.2	9.6	9.6	9.6	6.7	7.8	2.2	2.0	5.3

Based on the maximum yearly accumulation of snow water equivalent, the average percent of total annual precipitation at Buck Meadows, occurring as snowpack, is 72 percent. This varies from 53 percent to 93 percent and is not related to the magnitude of annual precipitation. The actual percentage of precipitation falling as snow is somewhat less since part of the snow water equivalent is due to rain-on-snow events.

The temperature regimes at the two climatic stations are similar (figure 3). Generally, the summer temperature fluctuation at Buck Meadows is less and the winter temperature is slightly higher than at Lower Horse Creek. Average maximum temperatures occur in July (60°F mean daily temperature) and minimun temperatures occur in January (23°F mean daily temperature).

HYDROLOGY

The hydrographs of the East and Main Forks of Horse Creek are characterized by large increases in stream discharge during snowmelt. There is at least an order of magnitude difference in discharge on an annual basis. Peak discharge usually occurs in May and drops off to lowest discharges in September. Fall rains and occasional winter melt cause a slight increase in discharge from October through March.

The variability in stream flow from year to year is quite high as a result of annual differences in precipitation (figures 4 and 5). The East Fork watershed has an average annual discharge of 5360 acre-feet (3.2 square mile inches) and the Main Fork, 6805 acre-feet (3.5 square mile inches). The average ratio of discharge to total precipitation is 0.44 and 0.40 for the Main and East Forks, respectively.

INSTRUMENTATION

In 1965 Parshall flumes, Stevens A-35 stage recorders, and bedload catch basins were installed at the mouths of the East and Main Forks of Horse Creek. Climatic stations consisting of hydrothermographs, Stevens Q-12M weighing precipitation gages, and anemometers were installed near the confluence of the East and Main Forks and at a site in the headwaters of the Main Fork Drainage. The following year four snow depth markers were located in Horse Creek to be used in conjunction with a snow survey course established in 1964.

In 1973 and 1974, H-flumes, Stevens A-70 stage recorders and bedload catch basins were installed at the mouths of ten south aspect subdrainages in the Main Fork Drainage.

In 1976, 1977, and 1978, six additional climatic stations with weighing precipitation gages and hydrothemographs were installed in the Main Fork Drainage. The present network of climatic stations consists of four stations along the long axis of the watershed in the valley bottom and four stations that transverse the watershed from ridge tops to valley bottom to ridge top.

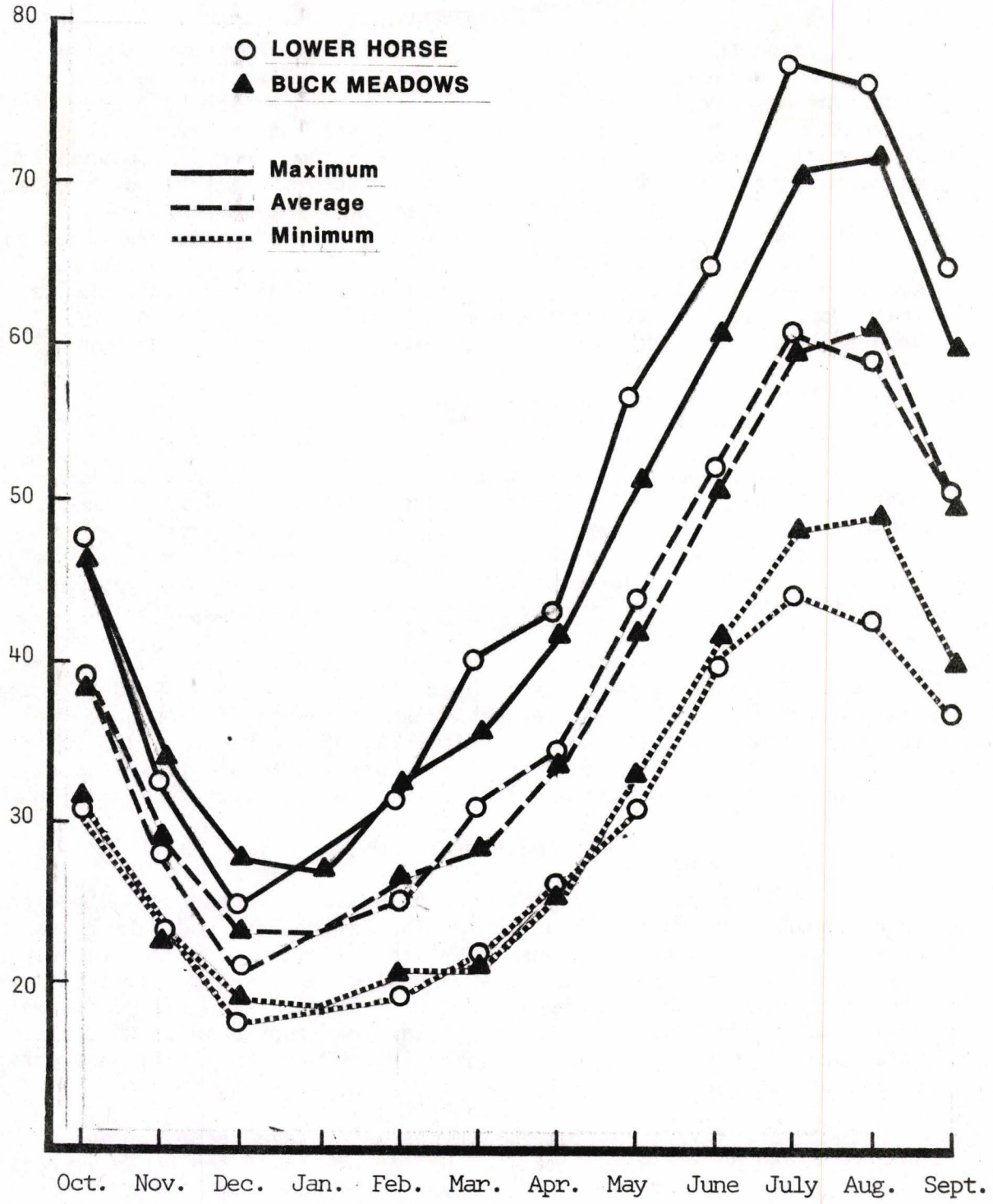

Figure 3. Mean and extreme monthly temperatures at Lower Horse and Buck Meadows climatic stations for the period 1966-1976.

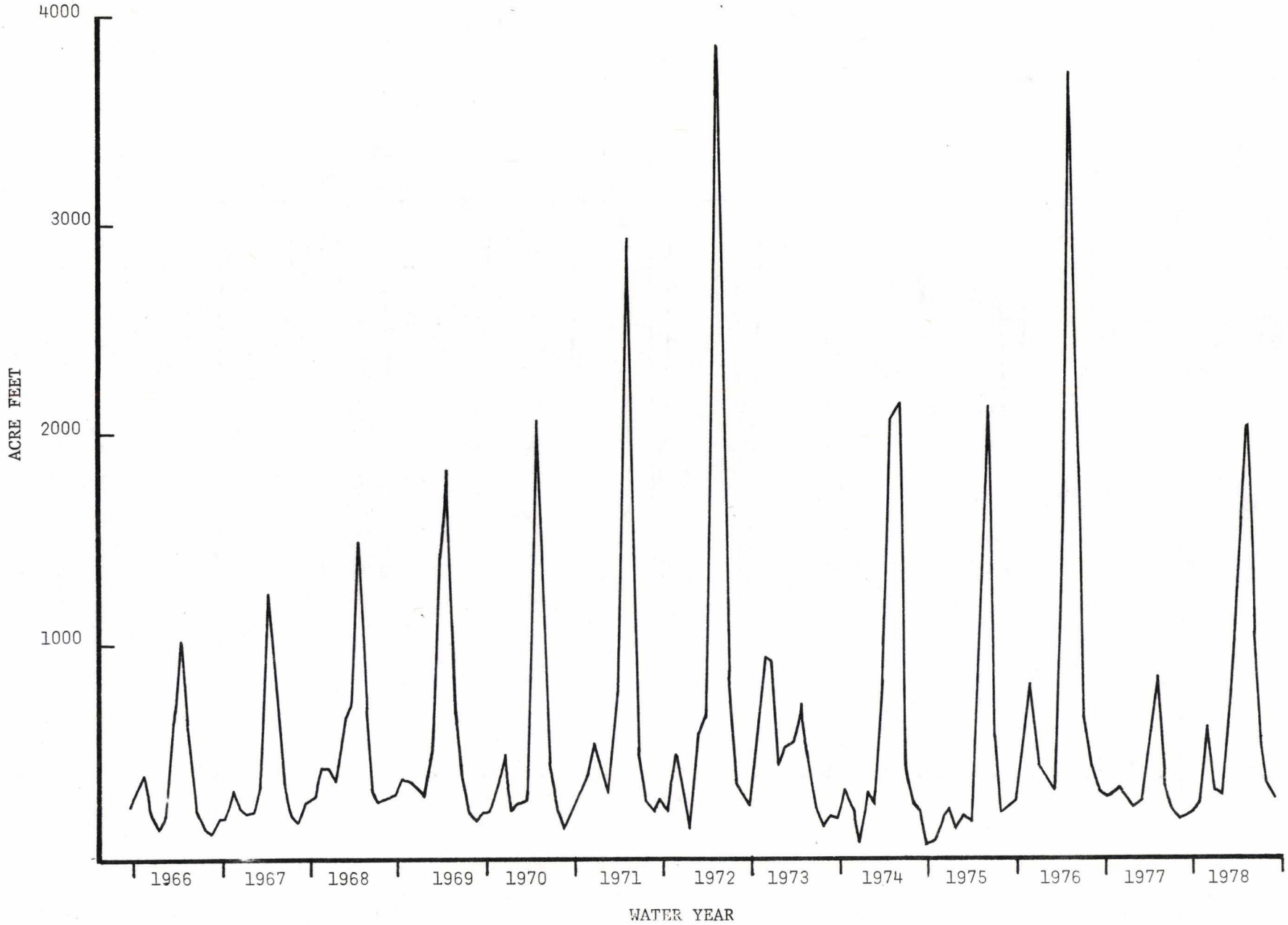

Figure 4. Stream flow variability, water years 1966-1978, for the Main Fork of Horse Creek.

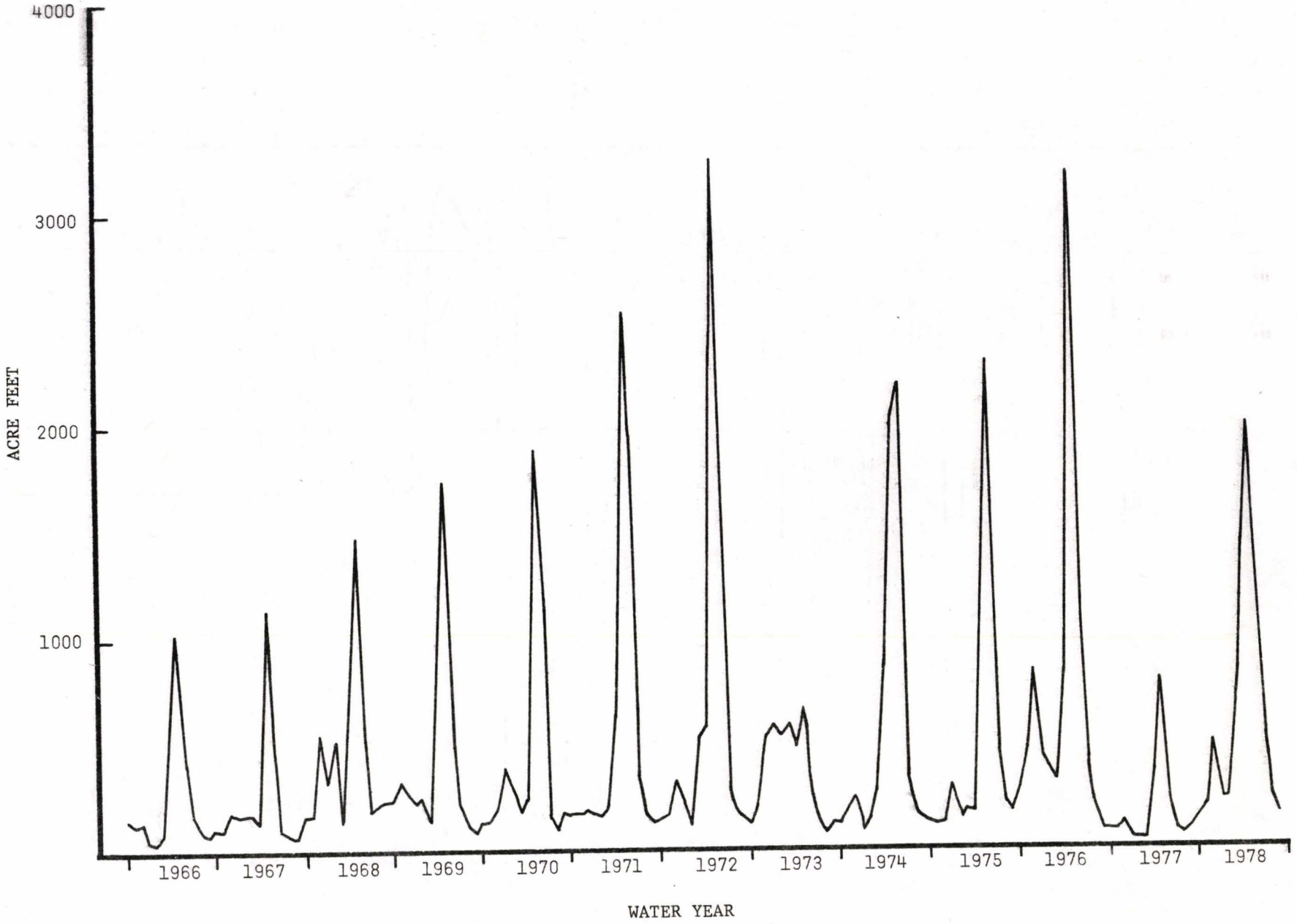

Figure 5. Stream flow variability, water years 1966-1978, for the East Fork of Horse Creek.

In 1978, H-flumes, Stevens A-35 and A-70 stage recorders, and bedload catch basins were installed on five north aspect watersheds in the Main Fork Drainage.

Additional instrumentation, specific to given studies, have been installed in the Main Fork Drainage. The types of instrumentation is presented with the discussion of the individual studies in subsequent sections.

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SECTION 3

NATURAL STREAM CHEMISTRY

Natural Stream Chemistry

INTRODUCTION

This section discusses one study that investigated the outflow of various dissolved ions in relation to stream discharge and the total annual yields of the ions. These relationships are discussed along with the influence of physical characteristics of the watersheds on the ion concentration versus stream discharge relationships (rating curves). The purpose is to express the results in a summary form that conveys the chemical characteristics and processes of the Horse Creek streams. A more detailed presentation is available in King (1979).

The sources of dissolved nutrients to streams are the atmosphere; precipitation, absorption of gasses, and dry fallout; geologic weathering and biological decomposition. Supply rates of the various ions vary temporally and spacially as precipitation and temperature regimes change which directly affect weathering and decomposition rates.

The geology and soil type of the site have the dominant effect on the concentrations of the various ions. The rate of supply to the stream of a specific ion is a function of its supply rate in the weathering of the soil parent material-organic matter complex and its ability to be transported via subsurface flow to the channel.

The concentration of a specific ion is not only a function of the supply rate to the stream but also of stream discharge. For a constant rate of supply, the concentration is inversely related to discharge. Hem (1975) expressed this dilution effect in the following equation:

$$Y = aX^b$$

where Y = concentration of a specific ion, mg/l (1)

X = stream discharge, ft^3/sec

a, b = constants

This equation can be expressed as a linear regression model by logarithmic transformation:

$$\log_{10} Y = \beta_0 + \beta_1 \log_{10} X + \varepsilon \quad (2)$$

where β_0, β_1 = regression coefficients

ε = error

This regression model was used in evaluating the relationships between stream discharge and dissolved chemicals in the Horse Creek streams.

METHODS

During 1975, 1976 and 1977 one liter stream water samples were collected at the mouth of the ten south-facing Horse Creek Subdrainages. Samples were collected twice a week during the spring and early summer and monthly the remainder of the year.

Field determinations were made of stream temperature, pH, specific conductivity, and alkalinity. Samples were cooled and transported to the University of Idaho where determinations were made of pH, specific conductance, alkalinity, magnesium, calcium, potassium, nitrate, phosphate and sulfate using approved methods (Standard Methods 1971, EPA 1974).

ANALYSIS AND RESULTS

The streams in these ten subdrainages are well shaded by streamside vegetation. In addition, the lower reaches receive a varying degree of topographic shading. Peak summertime stream temperatures were approximately 16° C with winter minimum temperatures of slightly below freezing. No analysis was performed on stream temperature data; however, this baseline data can be used for comparison following subsequent harvesting.

These streams have very low concentrations of dissolved ions (Table 1). Nitrate nitrogen and phosphate phosphorus, two important nutrients for periphyton growth, were extremely low. The ion with the highest concentration in these streams was sodium, a relatively mobile monovalent ion.

RELATIONSHIP TO STREAM DISCHARGE

The concentrations of Ca^{++}, Mg^{++}, K^{+}, Na^{+}, alkalinity, and the specific conductivity values were inversely related to stream discharge using equation 2 (Table 1). The sulfate concentrations only exhibited a significant inverse relationship in four of the ten streams. Thus, as stream discharge increases, predominately during snowmelt, the concentrations of the ions diminish due to dilution. The ranges and means for the regression coefficients for the individual rating curves are shown in Table 2. Nitrate nitrogen concentrations were usually below 0.1 mg/l, the lowest detectable limit for the laboratory method used. Therefore, the relationship between nitrate nitrogen and stream discharge could not be analyzed. The relationship between pH and stream discharge was statistically significant, but this researcher places little reliability in these relationships due to measurement problems.

Table 1. General information on the relationships between stream discharge and water chemistry for 1975 and 1976 using equation 2.

Chemical Parameter	Relationship to Stream Discharge	Range of Coefficient of Determination	Range of Concentration	Units
pH	inverse	--	6.1 to 8.8	pH units
NO_3-N	1/	--	< 0.1 to 0.64	mg/l
PO_4-P	not related	--	0.001 to 0.076	mg/l
SO_4^{++}	inverse 2/	0.09 to 0.15	1.11 to 6.00	mg/l
Alkalinity	inverse	0.25 to 0.88	9.56 to 30.50	mg/l as $CaCO_3$
Calcium	inverse	0.16 to 0.54	0.36 to 4.00	mg/l
Magnesium	inverse	0.10 to 0.46	0.22 to 3.39	mg/l
Potassium	inverse	0.15 to 0.38	0.53 to 1.75	mg/l
Sodium	inverse	0.09 to 0.78	1.52 to 4.74	mg/l
Specific Conductivity	inverse	0.36 to 0.81	15 to 35	micromhos/cm at 25° C

1/ The relationship to discharge was not determined due to numerous samples having concentrations below detection limits.

2/ Only four of the ten streams had SO_4^{++} rating curves that were significant.

Table 2. Range and mean of the regression coefficients from equation 2 for the various chemical parameters.

Chemical Parameter	Range $\hat{\beta}_0$	Mean	Range $\hat{\beta}_1$	Mean
SO_4^{++}	0.24 to 0.31	0.273	-0.10 to -0.05	-0.065
Alkalinity	0.25 to 1.26	1.079	-0.19 to -0.06	-0.137
Ca	-0.19 to 0.14	-0.007	-0.27 to -0.09	-0.208
Mg	-0.41 to -0.01	-0.208	-0.21 to -0.08	-0.146
K	-0.06 to 0.00	-0.016	-0.16 to -0.04	-0.085
Na	0.27 to 0.04	0.383	-0.16 to -0.06	-0.113
Specific Conductance	1.30 to 1.55	1.417	-0.25 to -0.09	-0.162

EFFECT OF WATERSHED CHARACTERISTICS

Several physical characteristics of the subdrainages aided in explaining differences between their respective rating curves. The regression coefficients from the dissolved chemical rating curves were correlated with a group of subdrainage descriptors. The watershed descriptor that was best correlated with each regression coefficient (equation 2) is shown in table 3. The two descriptors that were repeatedly best correlated with the regression coefficients are the lemniscate constant, a shape descriptor, and the relief ratio, an index of watershed steepness.

The rating curves for alkalinity, calcium, sodium, and specific conductivity are influenced by the shape of the watershed. Their intercept coefficients, β_0, were inversely correlated with the lemniscate constant. The lemniscate constant (K) is a function of the maximum basin length (L_b) and the watershed area (A).

$$K = \frac{L_b^2 \pi}{4A}$$

Table 3. Physical descriptors of the Horse Creek Watersheds that were best correlated to the regression coefficients for the water chemistry rating curves.

Chemical Parameter	$\hat{\beta}_0$	$\hat{\beta}_1$
Alkalinity	lemniscate constant $R = -0.59$ $\alpha = 0.1$	relief ratio $R = 0.89$ $\alpha = 0.01$
Calcium	lemniscate constant $R = -0.69$ $\alpha = .05$	relief ratio $R = 0.71$ $\alpha = 0.05$
Magnesium	--	relief ratio $R = 0.91$ $\alpha = 0.01$
Potassium	relief $R = 0.61$ $\alpha = 0.1$	relief ratio $R = 0.60$ $\alpha = 0.1$
Sodium	lemniscate constant $R = -0.80$ $\alpha = 0.01$	drainage density $R = 0.68$ $\alpha = 0.05$
Specific Conductivity	lemniscate constant $R = -0.62$ $\alpha = 0.1$	relief ratio $R = 0.79$ $\alpha = 0.01$

The slope coefficients, $\hat{\beta}_1$, for the alkalinity, calcium, magnesium, potassium, and specific conductivity rating curves were significantly and positively correlated with the subdrainge relief ratio. The relief ratio is the total subdrainage relief divided by the maximum length of the watershed.

Those Horse Creek Subdrainages with the greatest lemniscate constants and the greater relief ratios typically had lower concentrations of alkalinity, calcium and sodium, and lower specific conductivities. These watersheds did not exhibit as great a change in water chemistry throughout their range of stream discharge as the other watersheds. Potassium and magnesium concentrations in these three watersheds were less than in other watersheds for similar low discharges.

The inherent cause-effect relationships that lead to these correlations between the physical characteristics and the rating curve coefficients are not known. However, it would appear that it may be related to the rate of travel of dissolved chemicals through the soil mantle to the stream channel. Thus, watershed characteristics may influence the rate of supply of a specific ion to the stream.

EFFECT OF DROUGHT

During water year 1977 the Horse Creek subdrainages had extremely low discharges due to drought conditions. Total yields of streamflow were less than 50 percent of normal. The relationships between chemical concentrations and discharge were usually much different during 1977 than the two previous years.

Higher concentrations or levels of each water chemistry parameter, except pH, were measured during 1977. This was partially due to a decreased dilution effect of the stream discharge. Alkalinity, calcium, sodium and potassium concentrations, and specific conductance levels were higher than would have been predicted using the rating curves developed in 1975-1976. This was especially apparent at lower discharges and on the three smallest subdrainages. The largest change occurred in the calcium rating curves. At a discharge of 1.0 ft^3/sec, the concentration was on the average 4.7 times as great as predicted from the 1975-1976 relationships. For the three smallest watersheds, calcium concentrations at 1.0 ft^3/sec were 7.2 times as great.

During 1977 there was a noticeable inverse relationship between chemical concentrations and stream discharge, but in many instances these relationships were not statistically significant. Only for alkalinity and specific conductance were the relationships with discharge significant for all of the Horse Creek Subdrainages. The lack of a significant relationship for other parameters may partially be due to the small range of stream discharges during 1977.

ANNUAL YIELDS

Annual yields (lbs/mi^2) of the various ions were determined using their respective rating curves (equation 2) and the mean discharges for the ten subdrainages (table 4). There was considerable variation in yields per unit area between subdrainages for any given water year. Between water years, there was also considerable variation in the yields per unit area of the dissolved chemicals. However, much of this variation between years is related to the total annual stream discharge. For all dissolved ions except calcium, as water yields increased, the annual outflow of the ion (lbs/mi^2) increased (fig. 1). The outflow of the calcium, however, was greatest during 1977, the year of lowest stream discharge.

SUMMARY AND CONCLUSIONS

The streams draining the Horse Creek Subdrainages have low concentrations of dissolved chemicals. Buettner and Falter (1978) investigated the water chemistry of selected streams in the Idaho Primitive Area. Two of the streams they studied were underlain with precambrian belt series formations, similar to the parent material in Horse Creek. The chemical concentrations in the headwaters of the streams were similar to those of Horse Creek streams. Thus, the geology of an area plays a predominant role in influencing stream water chemistry.

As stream discharge increases, the concentrations or levels of many of the water quality parameters decrease due to dilution. In this study, pH, sulfate, alkalinity, calcium, magnesium, potassium, sodium, and specific conductivity were inversely related to stream discharge using the following model:

$$\log_{10} Y = \beta_0 + \beta_1 \log_{10} X + \varepsilon$$

where Y = concentration or level of the chemical parameter

X = stream discharge

ε = error

During the drought of 1977 higher concentrations or levels of the water chemistry parameters were measured than would have been predicted using the 1975-1976 rating curves. Thus, these high concentrations cannot be attributed completely to a change in the dilution effect.

The relationships between discharge and water chemistry were not similar between watersheds. The three smallest watersheds, characterized by high relief ratios and high lemniscate constants typically had lower concentrations of any parameter than the other watersheds at similar discharges.

Table 4. Annual yields (lb/mi^2) of dissolved ions for the ten Horse Creek Watersheds.

Chemical Parameter	1975 Range	1975 Mean	1976 Range	1976 Mean	1977 Range	1977 Mean
			(lb/mi^2)			
PO_4-P	17-140	79	28-40	93	-- --	--
SO_4^{++}	3912-9227	5729	6275-13599	8651	-- --	--
Alkalinity as $CaCO_3$	23667-60058	44153	38530-90812	66064	9050-41203	23840
CA	1931-4035	3043	3057-6125	4252	2940-9324	6172
MG	1061-2863	1823	1737-4310	2725	430-1283	947
K	1942-3549	2782	3151-5093	4183	922-2214	1587
NA	4041-10207	7020	6695-14615	10553	1745-6181	3595

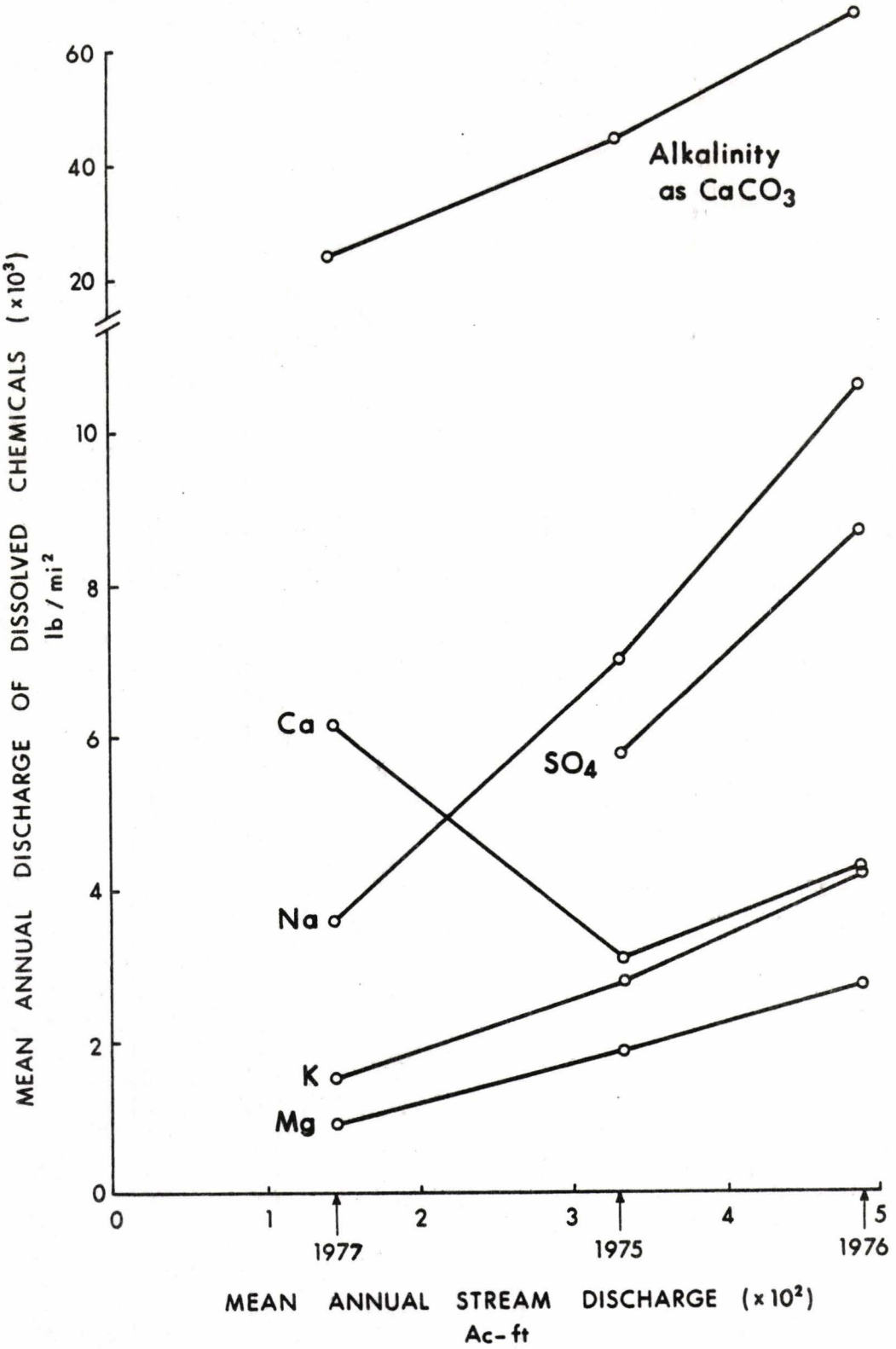

Figure 1. Mean annual stream discharge versus mean annual outflow of dissolved chemicals. (Data points represent the averages for the ten Horse Creek subwatersheds.)

The annual yields of any ion on a unit area basis varied between watersheds and between years. Differences in yields between years are attributed to differences in water production. For all of the ions, except calcium, as annual water production increased there was a corresponding increase in the annual yield of the specific ion. However, this should only be viewed as a trend since there were only three years of data available.

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SECTION 4

NATURAL STREAM SEDIMENT

INTRODUCTION

This section will report the findings on sediment transport, yield and physical characteristics from gaged subdrainages in the Main Fork of Horse Creek Drainage (fig. 1).

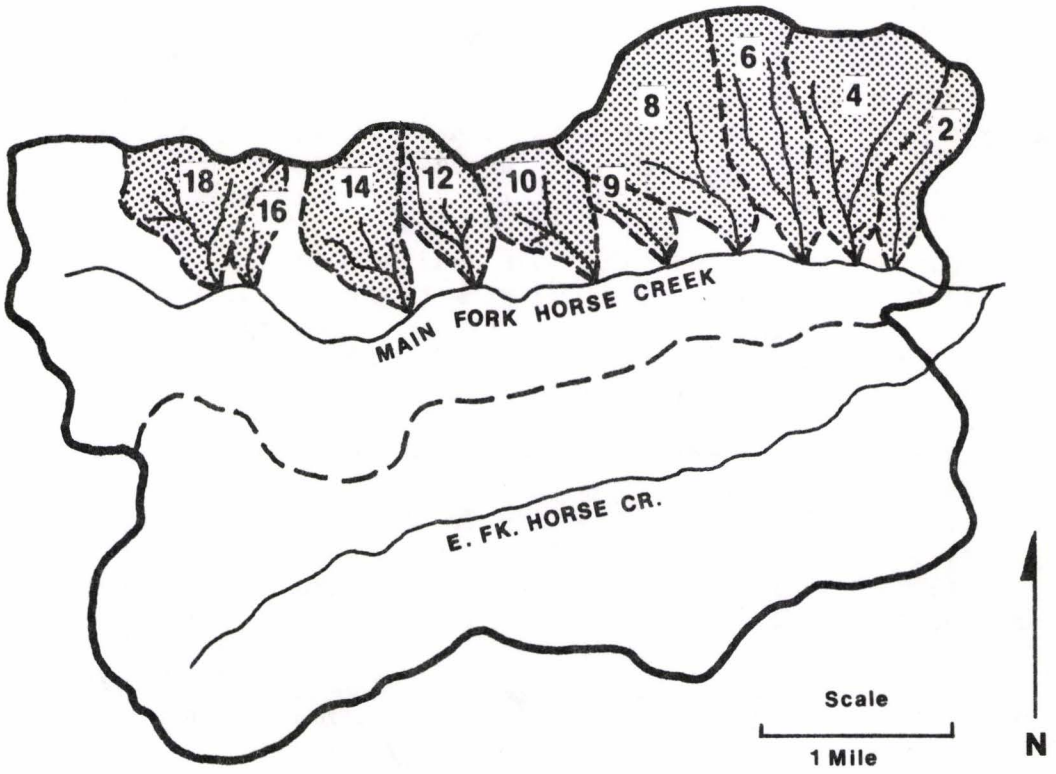

Figure 1.--The location of the ten gaged subwatersheds in the Main Fork of Horse Creek drainage.

The sediment transported to the mouth of the watersheds is believed to be derived chiefly from channel erosion. Others (Rosgen 1975; Anderson 1975; Megahan 1976) have found that for forested drainages, the predominant source of sediment is from channel erosion. There is no visual evidence of surface erosion within these watersheds. However, there are numerous old scarps and other indicators of localized mass movement of the soil mantle. Creep processes may also be occurring on these steep slopes. These mass movement processes deliver soil to the channel where bank erosion occurs. The relative contributions of sediment from channel bottom erosion versus bank erosion are not known.

FIELD METHODS

Forest Service personnel installed H-flumes, stage recorders, and debris basins at the mouth of the ten watersheds which have provided continuous stage (discharge) and annual volumes of deposited sediment data since water year 1975 and for several watersheds since 1974.

During water years 1975, 1976, and 1977 bedload sediment transport rates were measured using a Helley-Smith portable sampler. Samples were taken twice a week during periods of high discharge. As discharge decreased, sampling was less frequent. No bedload samples were collected once summer low flows were reached.

Stream water samples were collected during water years 1975, 1976, and 1977 and filtered (pore size = 1.45 microns) to determine suspended sediment concentrations. Sampling frequency was the same as for bedload sediment transport except samples were also collected monthly during late summer, fall, and winter. Samples were collected at both the inlet and outlet of the sediment debris basins.

Core samples of sediment deposited in the debris basins and samples of bedload material from the Helley-Smith samplers were analyzed for percent organics and size distribution of the mineral particles.

BEDLOAD SEDIMENT

The relationship between bedload transport rates and stream discharge has been shown to be parabolic (Johnson and Smith 1977). This can be expressed as :

$$Y = aQ^b$$

where Y = bedload transport rate, gms/hour (1)
Q = stream discharge, ft^3/sec

a, b = coefficients

This model (1) was logarithmically transformed to create the following linear regression model:

$$\log_{10} Y = \beta_0 + \beta_1 \log_{10} Q + \varepsilon \qquad (2)$$

where ε = regression error

β_0, β_1 = regression coefficients

This regression was used to relate stream discharge and bedload transport rates for each watershed for 1975 and 1976. In all but one instance, bedload transport was directly related to stream discharge ($\alpha = 0.1$), and for all but one watershed, the 1975 model was statistically similar to the 1976 model ($\alpha = 0.10$) (table 1). The 1975 and 1976 data were combined to generate a single model for each watershed. The coefficients of determination, R^2, for these models ranged from 0.78 to 0.97. The range of values for the regression coefficients in equation 2 for the two years of data combined were:

$$\underset{\text{mean} = 2.343}{\text{Log}_{10} Y = (1.485 \text{ to } 3.241)} + \underset{\text{mean} = 2.57}{(1.877 \text{ to } 3.045)\ \text{Log}_{10} Q}$$

Using the mean coefficients for the ten watersheds, if discharge is doubled, the bedload transport rate increases by a factor of 5.9 times.

Many of the watersheds with similar physical characteristics exhibited similar relationships between discharge and bedload transport. Correlation anaylsis using the regression coefficients (equation 2) and watershed descriptors revealed that the β_0 coefficient was best correlated to watershed area and the β_1 coefficient was best correlated to the watershed relief ratio. In regression form these relationships are expressed as follows:

$\hat{\beta}_0 = 3.3986 - 0.0054$ Area (acres) $\qquad R^2 = 0.78 \qquad \alpha = 0.01$

$\hat{\beta}_1 = 4.8440 - 9.0101$ Relief Ratio $\qquad R^2 = 0.47 \qquad \alpha = 0.05$

For these Horse Creek Watersheds, the smaller the area, the greater the rate of bedload transport for a given discharge. Also the steeper watersheds, as indexed by greater relief ratios, do not increase their bedload transport rate with increasing discharge as much as the less steep watersheds. Figure 2 shows typical relationships between bedload transport and discharge for three groupings of watersheds. Group II represents the larger watersheds with the lower relief ratios, and Group III represents the smaller watersheds with the greater relief ratios. The models within each group were statistically similar. Group I watersheds are of intermediate size and relief.

Table 1. Regression coefficients and statistical information for the bedload transport versus stream discharge relationships for the 1975-1976 data. (Model: $\log_{10} Y = \beta_0 + \beta_1 \log_{10} X + \varepsilon$; where Y = bedload transport, gms/hr and X = stream discharge, ft^3/sec; significance levels are **, $\alpha = 0.01$.)

Watershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Deviation	R^2	Significance
2	3.241	1.877	1.125	0.97	**
4	1.563	2.452	1.614	0.79	**
6	1.804	2.930	1.653	0.80	**
8	1.485	3.045	1.453	0.92	**
9	2.919	2.209	1.443	0.68	**
10	2.278	2.759	1.574	0.88	**
12	2.503	2.119	1.110	0.82	**
14	2.146	2.643	1.471	0.90	**
16	3.166	2.779	1.240	0.83	**
18	2.321	2.866	0.709	0.78	**

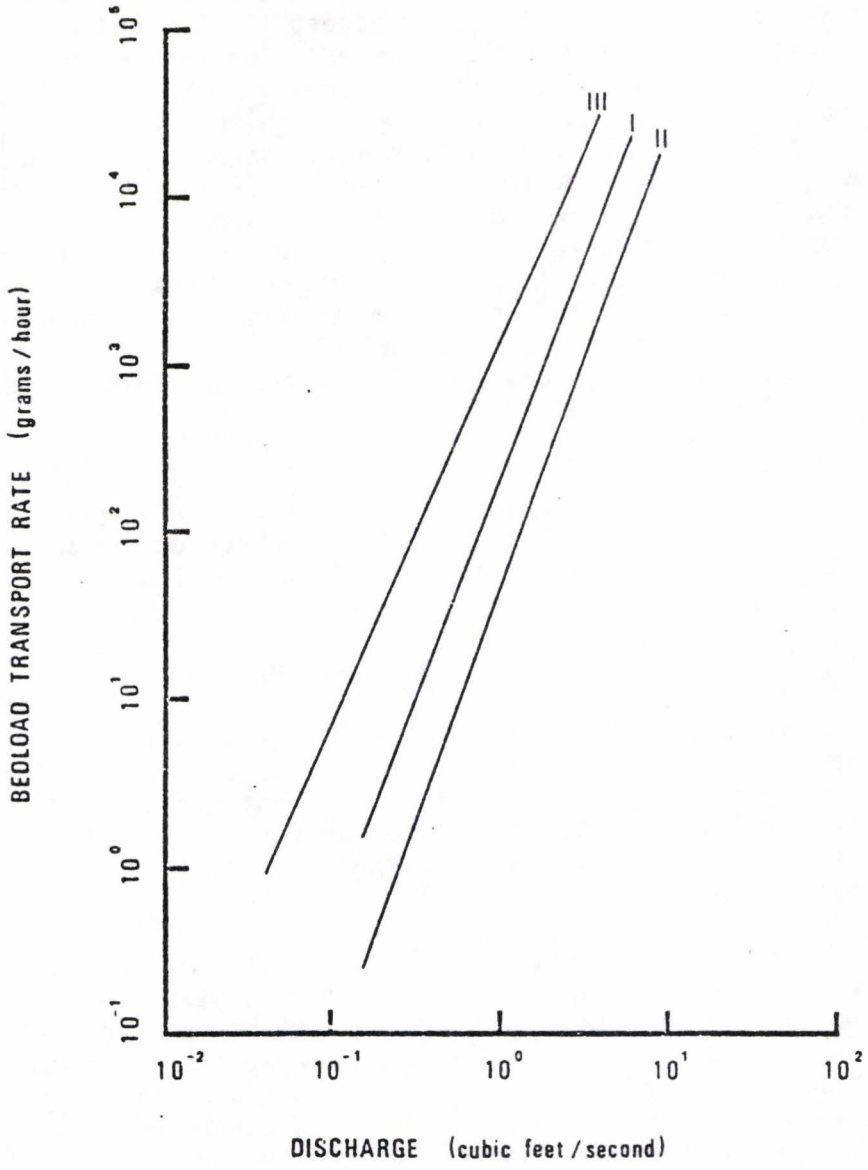

Figure 2. Bedload rating curves for the geomorphic groupings of the Horse Creek subwatersheds.

The distribution of particle sizes of transported bedload material is a function of the stream's transport ability and the upstream supply of sediment of different size classes. Generally, there was a trend of increasing particle size of transported material with increasing stream discharge. However, correlations between the median diameter and discharge were not always statistically significant. The median diameter, D_{50}, for bedload particles generally ranged from 0.4 mm during lower discharges to greater than 2.00 mm during peak discharges. Sand size particles, 0.05 to 2.00 mm, usually constituted the majority of the transported material. At peak discharges, gravels (> 2.00 mm) accounted for approximately 50 percent of the bedload, but accounted for only 5 to 15 percent near the end of the spring hydrograph. The silt and clay particles, > 0.05 mm, constituted only a small percentage of the transported bedload material (fig. 3).

The percentage of organic matter in the bedload samples was highly variable, ranging from 0.8 to 64.4 percent on a weight basis for the individual samples. Typically, the percentage of organics increased as stream discharge diminished on the recession limb of the snowmelt hydrograph.

SUSPENDED SEDIMENT

Past research has shown a direct relationship between suspended sediment concentrations and stream discharge (Farnes 1975; Piest 1963). Benedict (1948) suggests that these are not constant relationships; intensity of precipitation, rate of snowmelt, vegetation cover, channel stability, and shape of the watershed also govern suspended sediment concentrations.

The relationship between suspended sediment concentration and stream discharge is usually not linear. Equations 1 and 2, used for the bedload transport versus discharge relationships, were also used for the suspended sediment versus discharge relationships. These relationships were statistically similar for both 1975 and 1976. Therefore, the data were pooled to create one model for each watershed. All of these models were significant at $\alpha = 0.01$. However, the coefficient of determination, R^2, ranged from 0.28 to 0.67 indicating much more scatter than for the bedload relationships. Much of the variability within each of these relationships could be due to settling of airborne particles such as pollen and the influence of rainfall. These streams only appear turbid during intense rainfall events. Even during high snowmelt discharges the concentrations of suspended sediment remain relatively low (30-50 mg/l). The range of values for the regression coefficients (equation 2) were:

$$\underset{\text{mean} = 0.8038}{\text{Log}_{10}\, Y} = \underset{\text{mean} = 0.86}{(0.4267 \text{ to } 1.3058)} + (0.6057 \text{ to } 1.2791)\, \text{Log}_{10}\, Q$$

where Y = suspended sediment concentration, mg/l

Q = stream discharge, ft^3/sec

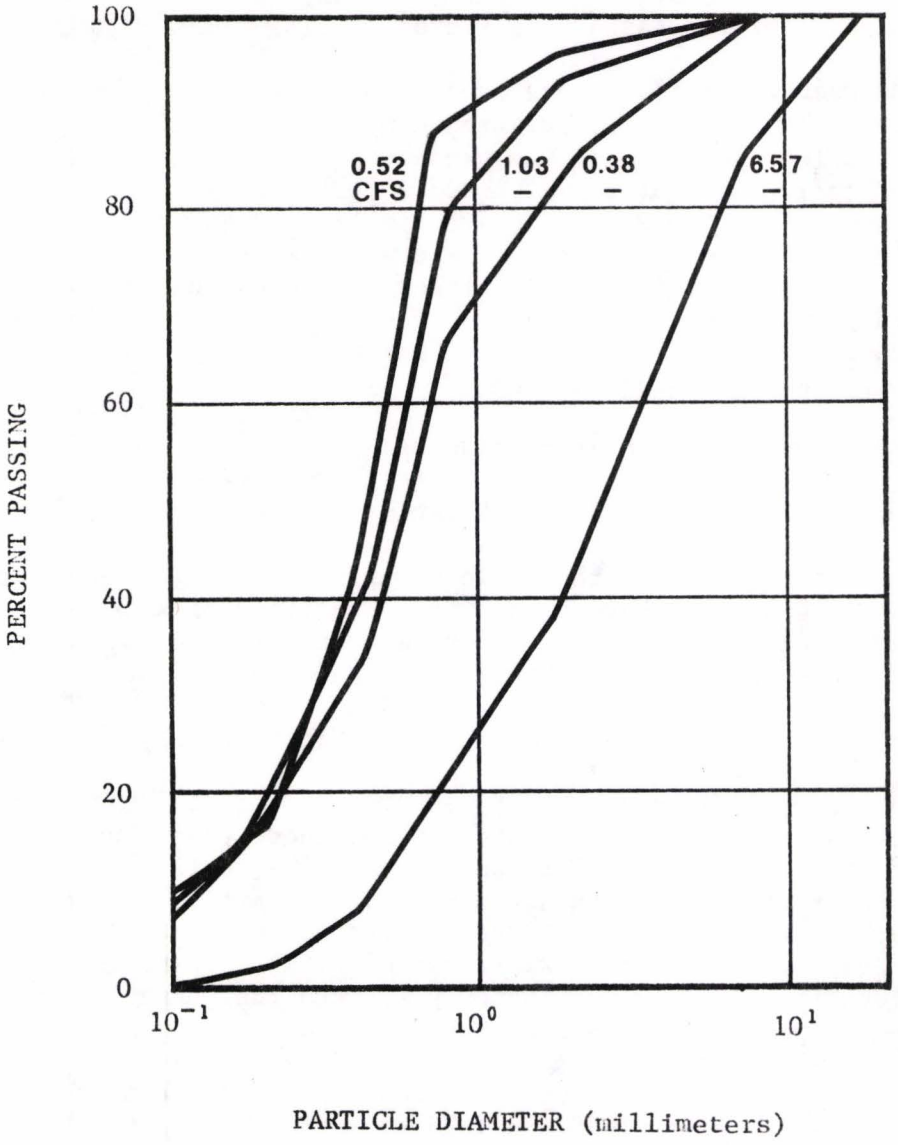

Figure 3. Particle size distribution of transported bedload material at four stream discharge levels for watershed 4 in 1975. Discharge rate is indicated in cubic feet/second.

Thus, there is a direct relationship between discharge and suspended sediment concentration (fig. 4). Using the mean values for all ten watershed models, as discharge doubles, the concentration of suspended sediment increased by a factor of 1.81 times.

Between watersheds there are large differences in the suspended sediment versus discharge relationships. For example, at a discharge of one cubic foot per second, the predicted concentration for watershed 8 is 2.67 mg/l while for subwatershed 9 it is 20.22 mg/l. The relationships for subwatersheds 2, 9, and 16 are similar and quite different than for the other watersheds (fig 4). These are smaller subwatersheds with high relief ratios and they produce higher concentrations of suspended sediment for any given discharge. The best predictors for the regression coefficients in equation 2 were watershed area and relief ratio as shown in the regressions below:

$\hat{\beta}_0 = 1.3924 - 0.0028$ Area (acres) $\quad R^2 = 0.76 \quad \alpha = 0.01$

$\hat{\beta}_1 = 2.2896 - 5.6721$ Relief Ratio $\quad R^2 = 0.61 \quad \alpha = 0.01$

As was evident for the bedload rating curves, the smaller subwatersheds generally have higher concentrations of suspended sediment for any given discharge and, as relief ratio increases, the slope of the rating curve decreases slightly.

TOTAL SEDIMENT YIELDS

Based on 1974 through 1978 measurements of sediment deposited in the debris basins, annual production for these ten subwatersheds ranged from a low of 0.92 yd^3/mi^2 to 253.17 yd^3/mi^2 (table 2). The average for all years for the ten watersheds was 35.5 yd^3/mi^2. Much of the variability between watersheds and between years can be explained by the annual water production from each watershed (fig. 5). There is a direct relationship between annual water yield and the annual volumes of sediment deposited in the debris basins.

Core samples of the deposited sediment were taken in four debris basins in water years 1975 and 1976 to quantify the physical properties of the sediment. The median diameter of the mineral particles in the debris basins ranged from 0.59 to 1.817 mm. Sand size particles (0.05 mm to 2 mm) accounted for 35 to 65 percent and 60 to 70 percent of the sediment on a weight basis for water years 1975 and 1976, respectively. Gravel size and larger particles accounted for 25 to 60 percent and 25 to 35 percent for 1975 and 1976, respectively. Silts and clays (< 0.05 mm) represented less than five percent for both years. Silts and clays, carried in suspension, are not efficiently trapped in these debris basins (fig. 6).

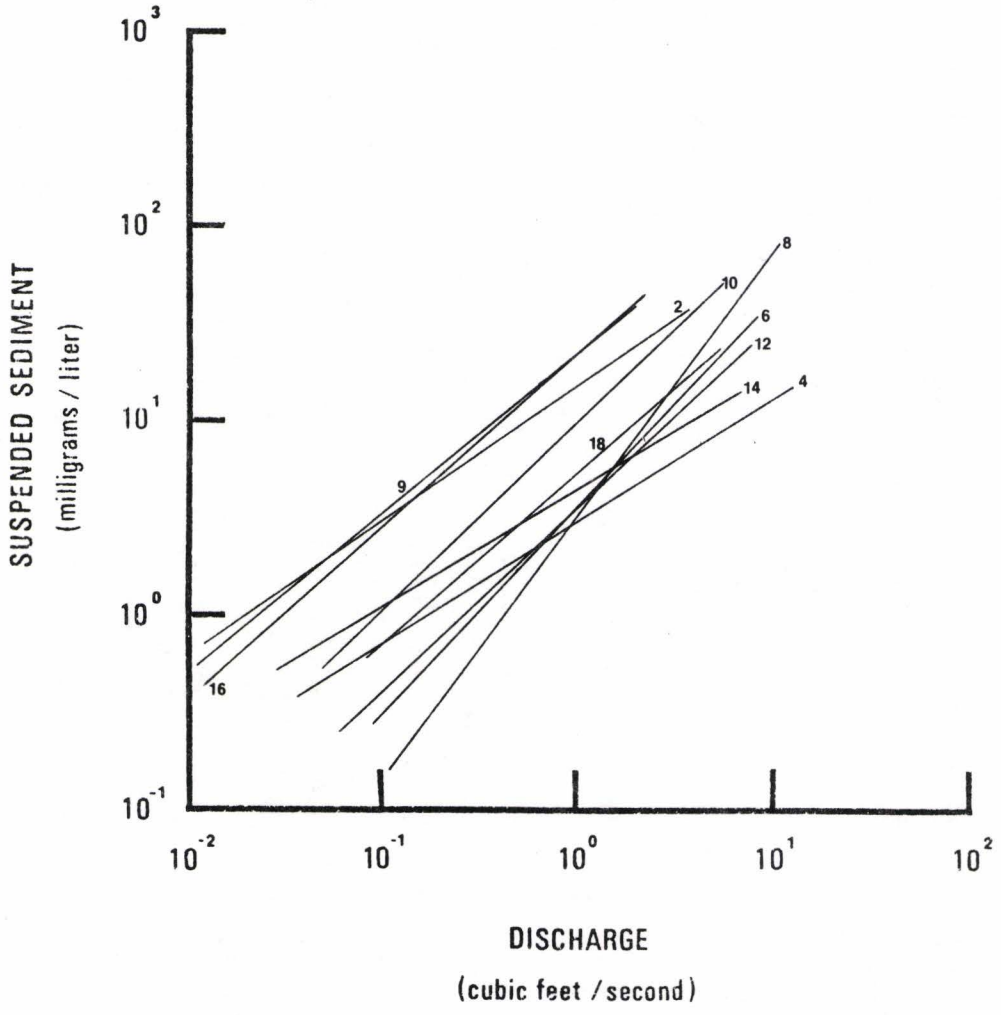

Figure 4. Suspended sediment concentrations versus stream discharge for the Horse Creek watersheds for water years 1975 and 1976.

Table 2. Annual sediment (yd^3/mi^2) measured in the debris basins for the Horse Creek watersheds during water years 1974 through 1978.

Water Year	Watershed 2	4	6	8	9	10	12	14	16	18	Mean	Standard Deviation
1974	--	--	15.9	--	--	--	--	--	53.7	34.6	34.7	18.9
1975	31.7	18.5	11.7	18.4	39.2	95.6	30.6	14.0	253.2	32.8	54.6	73.8
1976	77.2	29.3	21.9	35.0	32.9	57.6	43.1	30.5	36.2	46.4	41.0	16.2
1977	7.1	8.6	2.8	7.6	9.2	7.4	5.2	22.0	8.0	10.7	8.9	5.1
1978	46.3	10.0	14.9	33.8	48.3	46.7	32.8	47.2	78.0	45.8	40.4	19.2
Mean	40.6	16.6	13.4	23.7	32.4	51.8	27.9	28.4	85.8	34.1		
Standard Deviation	29.3	9.5	7.0	13.1	16.7	36.3	16.1	14.2	97.0	14.5		

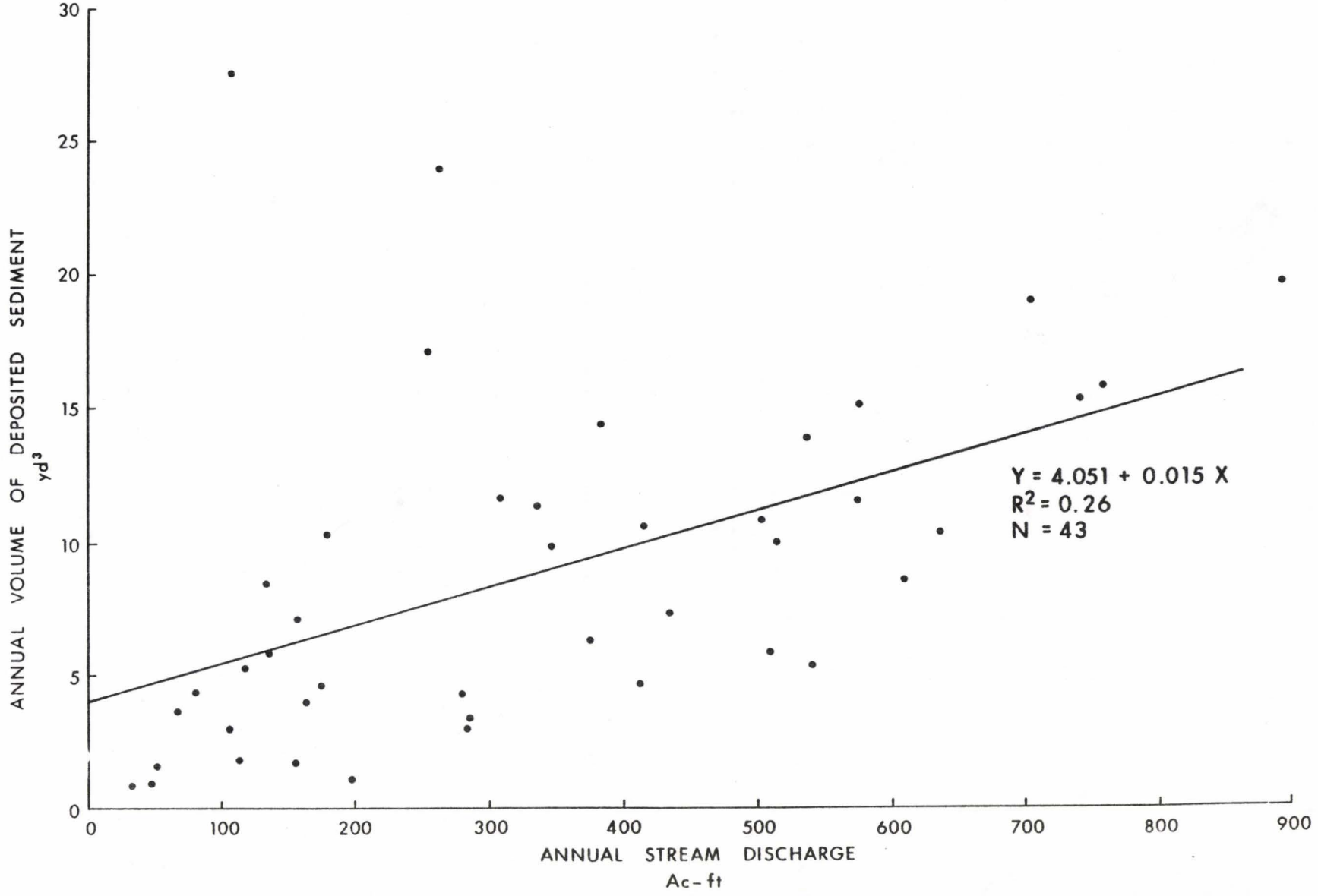

Figure 5. The relationship between annual stream discharge and annual volumes of sediment deposited in the debris basins for the ten Horse Creek subwatersheds.

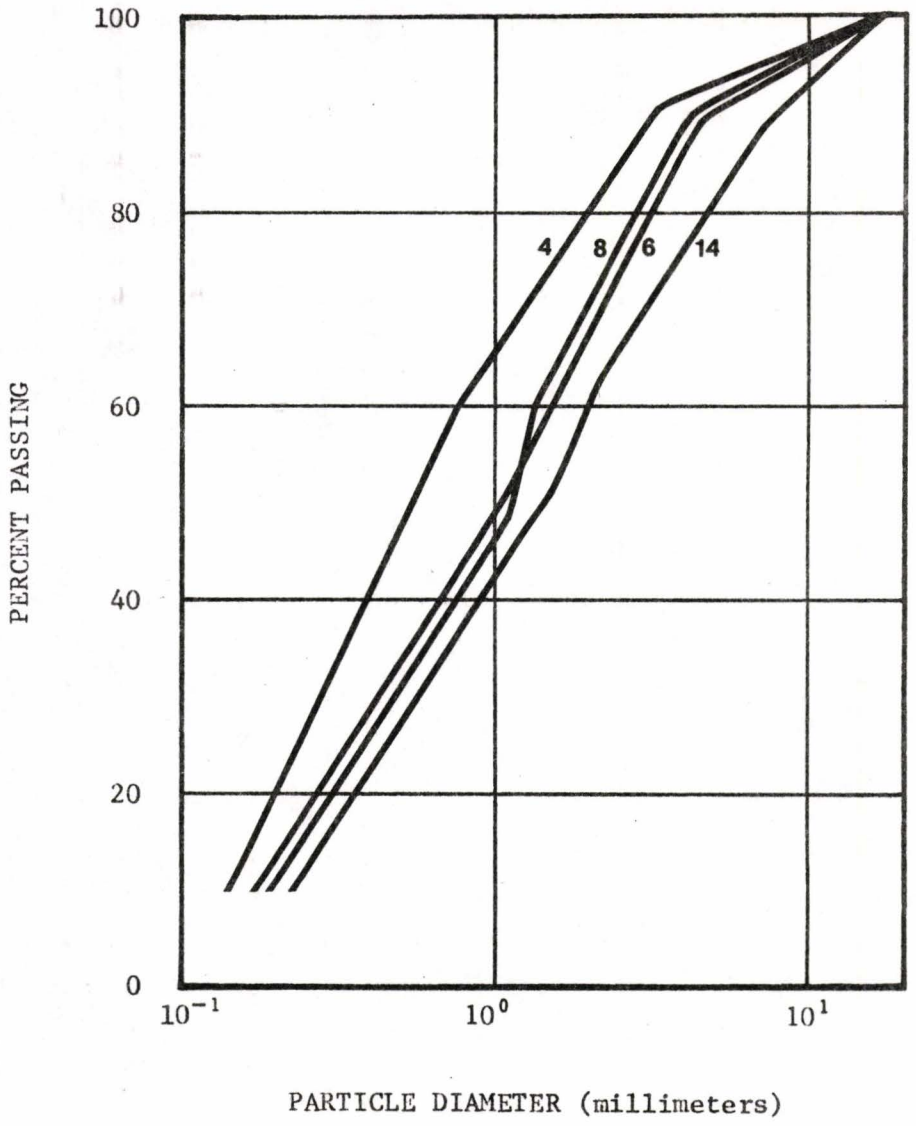

Figure 6. Mean particle size distribution for the deposited sediment in the debris basins on Horse Creek watersheds 4, 6, 8 and 14.

The mean percentage of organic matter for the four debris basins ranged from 4.4 to 17.2 percent on a weight basis, although for individual core samples the range was much greater, from 0.2 to 50.8 percent. There was considerable variability in the mean percent organics for the four debris basins; however, between years they had the same relative ranking.

The sediment volumes in the debris basins do not represent total annual sediment yields since most of the fines are not deposited. Total yields were estimated using the bedload and suspended sediment rating curves in conjunction with mean daily discharges for four selected watersheds (table 3). Suspended and bedload samples are not mutually exclusive; therefore, predicted volumes should be viewed as estimates.

Table 3. Predicted annual production (lbs) of suspended and bedload sediment for selected Horse Creek watersheds for water years 1975 and 1976.

Water Year		Watershed 4	6	8	14
1975	Bedload	4,719	6,102	10,274	4,410
	Suspended	8,575	10,275	24,293	12,842
	TOTAL	13,294	16,377	34,567	17,252
1976	Bedload	6,413	7,444	10,393	6,193
	Suspended	11,542	13,009	26,803	5,963
	TOTAL	17,955	20,453	37,196	12,156

Sediment transported in suspension accounts for 49 to 74 percent of the annual production. Thus, sediment transport in suspension is the dominant process in Horse Creek. The majority of sediment production occurs during snowmelt peak flows. The percentage of the total annual sediment production occurring during the three months of highest flows ranged from 91.0 to 98.9 percent for water years 1975 and 1976. Sediment production, especially bedload, is insignificant for the remainder of the water year.

In 1978 bulk densities of core samples in debris basins were measured in addition to particle size distribution and percent organics. This allowed for a better estimate of sediment production on a weight basis from the volume data collected in the debris basins. Megahan (1972) illustrated that the percentage of organics greatly influence the weight/volume relationship. A typical relationship between percent organics and weight/volume ratio is shown in Figure 7. Accurate estimates of sediment production on a weight basis require either measurement of bulk densities or percentage of organics in addition to volumetric measurement.

DROUGHT EFFECTS

Although stream discharges were very low in 1977, bedload transport rates were in general agreement with rates that would have been predicted using the relationships developed during 1975 and 1976. In general, the slopes of the 1977 relationships were steeper. Thus, in 1977, the increases in bedload transport with increasing discharge were greater than the previous two years. This may have been due to a larger volume of upstream sediment supply during 1977.

During 1977 suspended sediment concentrations were not significantly related to stream discharge. However, mean suspended sediment concentrations were generally higher during 1977 than would have been predicted using the 1975-1976 relationship.

The volumes of sediment in the debris basins were substantially smaller than the previous two years. Average production during 1977 was 8.9 $yd^3/mi^2/yr$ while during 1975 and 1976 it was 47.8 $yd^3/mi^2/yr$. Average stream discharges for the ten watersheds for 1977 and 1975-1976 were 145.8 acre feet and 408.4 acre feet, respectively.

STREAM CHANNEL EVALUATION AND INHERENT WATERSHED STABILITY

The Horse Creek watersheds were land typed by personnel on the Clearwater National Forest. These land types were used in the Clearwater Watershed Analysis Procedure (Bennett and Wilson 1975) to determine the "inherent watershed stability" for each watershed. The inherent watershed stability values ranged from 229 to 733 (mean = 509.6).

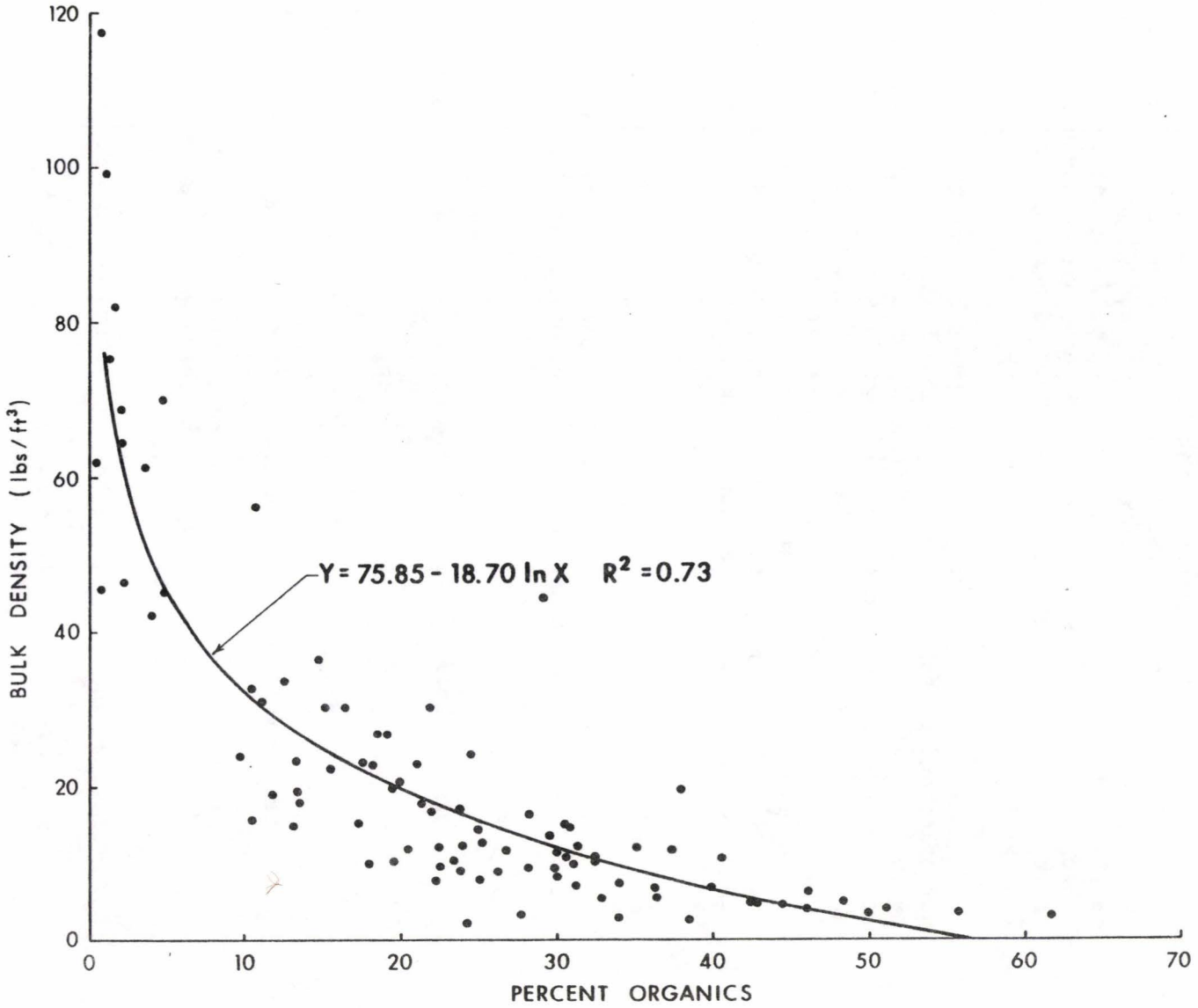

Figure 7. Percent organics versus bulk density for sediment cores from the Horse Creek debris basins in 1978.

In 1978, the hydrologist on the Nezperce National Forest walked the stream courses in each drainage and performed a stream channel evaluation (USDA Forest Service). The weighted channel evaluation ratings ranged from 86 to 105 (mean = 93.6). These ratings indicate fair channel conditions in this methodology.

A correlation anaylsis was done to determine the relationships between the inherent watershed stability, stream channel evaluation rating, and sedimentation variables. The sedimentation variables were: 1978 debris basin volumes expressed as yd^3 and yd^3/mi^2, mean 1975-1977 debris basis volumes expressed as yd^3 and yd^3/mi^2, and the regression coefficients, β_0 and β_1, for the suspended sediment and bedload sediment rating curves. Also included were watershed area, relief ratio, and lemniscate constant.

There were no significant correlations between the sediment yield variables and either the inherent watershed stability or the channel evaluation rating. However, the channel evaluation rating was significantly and positively correlated ($\alpha = 0.1$) with the β_0 coefficients for the bedload and suspended rating curves. Thus, shifts in the rating curves for a particular stream or differences in the rating curves between streams may be related to channel stability conditions as indexed by the channel evaluation rating. However, due to the small range in channel conditions found in Horse Creek, these observations are questionable.

SUMMARY

Bedload transport and suspended sediment concentrations are directly related to stream discharge using the following parabolic model:

$$Y = a\,Q^b$$

where Y = bedload transport (gm/hr) or suspended sediment (mg/l)

Q = stream discharge (ft^3/sec)

a,b = constants

These relationships were statistically significant and provide a means of predicting sediment transport rates or yields using stream discharge data. They also provide a means of evaluating management impacts. It is expected that shifts in these relationships will be evident following road construction and harvestings.

Differences in the models between watersheds are partially explained by the watershed area and relief ratio. The three smaller watersheds in Horse Creek are geologically more youthful than the others. They are

typically steeper watersheds which would indicate the potential for more rapid downcutting through channel erosion. These three watersheds transported more sediment for a given discharge than the other watersheds. Bedload sediment is comprised predominantly of sand size and larger particles, with a median diameter increasing as discharge increases. The percentage of organic matter transported as bedload was inversely proportional to discharge and was as high as 64 percent during lower flows. This may represent a significant outflow of nutrients from these watersheds.

Annual yields of deposited sediment in the debris basins averaged 35.5 yd^3/mi^2 for 1974 through 1978. This is similar to yields from undisturbed forested watersheds with coarse soils in Colorado (Leaf 1966) and central Idaho (Megahan 1972) where yields ranged from 0.3 to 20.5 yd^3/mi^2 and 4.5 to 11.8 yd^3/mi^2, respectively. However, the majority of sediment is transported in suspension in the Horse Creek watersheds and accounts for over 60 percent of the annual sediment yield. Approximately 23 percent of the suspended sediment is deposited in the debris basins. With this consideration, the Horse Creek watersheds, with finer textured soils, have a much higher annual sediment production than those reported by Leaf or Megahan.

During the drought of 1977, the bedload versus discharge relationships were similar to those developed the previous two years. However, there was not a significant relationship between suspended sediment and discharge during 1977, and concentrations were slightly higher than expected using the 1975-1976 models.

The "inherent watershed stability" and "stream channel evaluation rating" were not related to sediment yields. However, the stream channel evaluations were directly related to the β_0 regression coefficients for the bedload and suspended sediment rating curves.

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SECTION 5

ROAD CONSTRUCTION DETAILS

In 1978 and 1979 the roads to access the harvest units in the south facing subdrainages of the Main Fork Drainage were constructed. Four separate roads were constructed to totalling 7.343 miles. Figure 1 and Table 1 show the road locations and provide information on road length and road standard for each subdrainage.

There were two standards of roads constructed in these subdrainages and within each subdrainage the length of road is of a single standard. Standard 1 utilized road design criteria currently employed by the Nezperce National Forest. The objective of standard 1 design criteria is to provide for smooth traffic flow at a constant speed of 15 miles per hour. This necessitates careful consideration of alignment and curve radius. Horizontal and vertical alignment considered sight distance and grade breaks for relief of traffic flow, but did not consider grade breaks for relief of cut and fill slope height. The minimum curve radius was 110 feet and for curve widening, 400 feet. Subgrade, travelway, and ditch widths were 16, 12, and 3 feet, respectively.

This standard was applied to roads constructed in subdrainages 18, 16, 15, and 12. There were differences in the travelway, cut, and fill slope stabilization on roads in these three drainages. In drainages 18, 16, and 15 the travelway consists of 8 inches gravel and all cut and fill slopes were hydromulched, seeded and fertilized. Additionally, filter windrows of slash were placed on the lower portions of the fill slopes for at least 100 feet either side of a live water crossing.

In drainage 12 there was no travelway stabilization and no filter windrows at the live water crossings. Cut and fill slopes were not mulched or seeded.

Standard 2 design criteria does not consider smooth traffic flow, but rather attempts to minimize the cut and fill slope heights and "fit the terrain" to create a road with fewer erosion and drainage problems. The minimum curve radius was 50 feet and for curve widening 200 feet. Horizontal alignment provided for rolled grades for drainage relief and to minimize cut and fill slope heights. Subgrade, travelway and ditch widths were 15, 12, and 1 feet, respectively.

This standard was applied to roads constructed in drainages 14, 11, 10, and 8. In drainage 14 the travelway was asphalted and the cut and fill slopes were stabilized with a straw/asphalt tack mulch, seeded and fertilized. Filter windrows of slash were constructed at each live water crossing. In drainage 10 the travelway and cut slopes were not stabilized, nor were filter windrows constructed. Fill slopes were treated with seed and fertilizer, but were not mulched. In drainage 8, the travelway was stabilized with 8 inches of gravel, cuts and fills were seeded and fertilized and mulched with a straw/asphalt tack mulch. Straw bales were placed at the toe of the fill slopes for at least 100 feet on both sides of the stream crossing to impede soil movement to the stream.

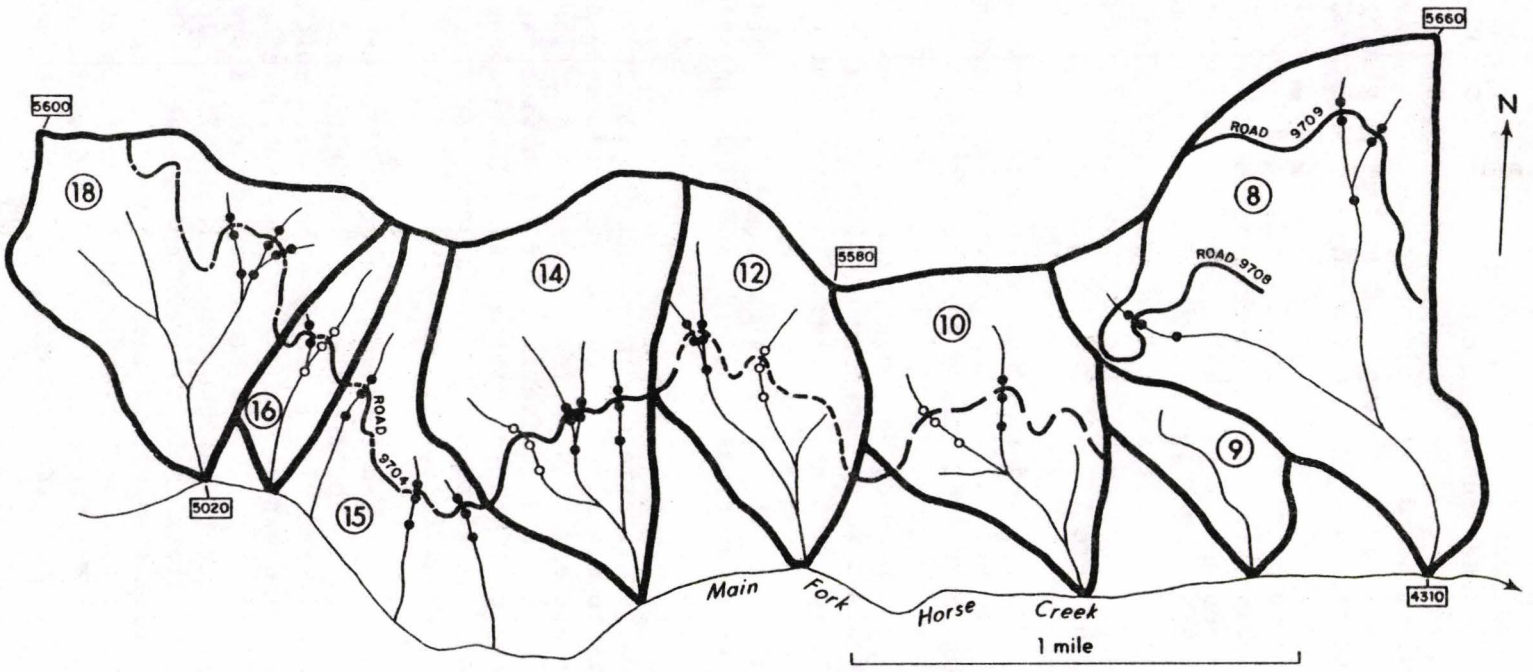

Figure 1. Road location and standard for the south facing drainages in the Main Fork of Horse Creek

Table 1.--Summary of standards by road number and drainage in the Horse Creek Administrative-Research Area.

Road Number	Drainage	Standard	Road Length (miles)	Road Density (miles/acre)
9704	18	1	0.944	0.0054
9704A	18	1	0.203	
9704	16	1	0.278	0.0040
9704	15	1	0.304	0.0040
9704	15	2	0.357	
9704	14	2	0.567	0.0039
9704	12	1	1.055	0.0050
9704	11	2	0.169	0.0027
9704	10	2	0.860	0.0052
9708	8	2	1.385	0.0071
9708	8	2	1.221	

Construction of the roads in drainages 18, 16, and portions of 15, and 8 were completed in 1978. In 1979 roads were constructed in the remainder of the drainages.

Additional specifications on the road standards and specific treatments are presented in the "Road Plans" prepared by the Nezperce National Forest and in the "Prospects of the Road Engineering Research" prepared by the Intermountain Forest and Range Experiment Station. Differences between standards or between the roads in specific drainages are discussed in subsequent sections of the report, where applicable.

SECTION 6

SEDIMENT PRODUCTION DURING ROAD CONSTRUCTION

SEDIMENT PRODUCTION DURING ROAD CONSTRUCTION

Measurements of stream discharge and sediment concentration were made during road construction activities, usually at the "A" and "C" stations at each stream crossing. In many instances, measurements were also made at the "B" stations and at the mouths of the watersheds, just above the debris basins. The total amount of sediment reaching each sampling point was calculated for each specific activity. There were no measurements made during the timber falling operation. Those activities monitored were road pioneering, permanent culvert installation, and in one instance, clearing right-of-way slash.

PIONEERING

The sedimentation consequences of road pioneering; the initial crossing of the stream and installation of a temporary culvert, were monitored during road construction in 1978 and 1979. The amounts of sediment produced from these activities at the various stations are shown in table 1. This table also includes the sedimentation effect of right-of-way slash clearing at stream crossing 18-1, the effect of installing a culvert on road 443.3 in watershed 16, which influences sediment concentrations in stream 16-2, and the sedimentation effects of road construction across a seep, 500 ft above the A station at crossing 8-1.

The amount of sediment reaching live water and transported downstream was highly variable. The care taken during pioneering, the length of time of pioneering at each stream crossing, the stream discharge, and unique site characteristics all influence the amount of sediment reaching the "B" stations. Downstream transport to the "C" stations and to the watershed mouths are a function of the stream's capacity to transport the available sediment and channel storage availability.

The amount of sediment reaching the "B" or "C" stations due to pioneering can be accurately determined by subtracting the amount measured at the "A" station from the amounts measured at the "B" or "C" stations. This method compared well with a different method, where the amount of sediment at the "C" station under undisturbed conditions was predicted based on stream discharge. This predicted quantity of sediment was then subtracted from the measured quantity to determine additions of sediment due to pioneering.

The amount of sediment reaching the "C" station as a result of pioneering activities, placement of a temporary culvert, ranged from 0.00 lbs to 212.59 lbs. At crossings 15-2 and 14-4 very little sediment was measured at the "C" stations. The stream discharges at crossings 15-2 and 14-4 were 0.006 and 0.004 $ft^3\ sec^{-1}$, respectively. Thus, these two streams were not capable of transporting any sediment derived from pioneering to the "C" stations. However, at crossing 8-2, with a considerably greater stream discharge of 0.02 $ft^3\ sec^{-1}$, there was also no measurable increase in sediment at the "C" station. Thus, the quantity of sediment

Table 1.--The sedimentation consequences of pioneering activities at selected stream crossings in the Horse Creek Watersheds

Stream Crossing	Installation Start Time	Installation Start Date	Monitoring[1] Finish Time	Monitoring[1] Finish Date	Station A Sediment lb	Station A Discharge ft^3 sec^{-1}	Station B Sediment lb	Station B Discharge ft^3 sec^{-1}	Station C Sediment lb	Station C Discharge ft^3 sec^{-1}	Mouth Sediment lb	Mouth Discharge ft^3 sec^{-1}
18-1[4]	1300	7-17-78	1955	7-17-78	0.06	0.02			1.72	0.04		
18-2	1400	7-17-78	1955	7-17-78	0.42	0.04	3.20	0.04	25.13	0.06	12.13 (9.19)[2]	0.92
18-3	1400	7-17-78	1955	7-17-78	0.01	0.01	2.04	0.01				
16-1	0800	7-11-78	0900	7-12-78	0.01	0.004	85.48	0.06	12.32	0.07		
16-2	0800	7-11-78	0900	7-12-78	0.88	0.06					2.58 (4.63)[2]	0.17
16-2[5]	0810	7-18-78	1040	7-18-78	3.28	0.06						
15-1	1715	6-14-79	1425	6-15-79	0.36	0.01			1.44	0.01		
15-2	1615	6-25-79	0945	6-26-79	0.10	0.004			0.06	0.006		
14-1	0900	6-27-79	0800	6-28-79	0.67	0.04			213.26	0.06		
14-2	0800	6-29-79	1500	6-29-79	0.03	0.04			41.51	0.04		
14-3	0800	6-29-79	1500	6-29-79	0.05	0.02						
14-4	1310	7-02-79	1600	7-02-79	0.02	0.006			0.003	0.004		
12-1	1225	7-09-79	1700	7-10-79	0.45	0.04	12.56	0.04	5.32	0.09		
12-2	1225	7-09-79	1700	7-10-79	0.32	0.03	2.81	0.03			11.20	0.21
12-3	1500	7-11-79	1300	7-13-79	1.51	0.02	154.71	0.02	112.20	0.03	(3.19)[2]	
8-1[3]	0910	7-24-78	0640	7-25-78	33.85	0.03			7.65	0.03		
8-2	0820	8-08-78	1200	8-08-78	0.02	0.02			0.02	0.02		
8-3	0820	8-08-78	1200	8-08-78								

1/Monitoring duration at the "A", "B", and "C" stations. The duration of monitoring at the mouths was considerably longer.
2/Values in parenthesis are predicted amounts of sediment for undisturbed contisions.
3/Monitoring the effects of pioneering in a seep area above the "A" station.
4/Effects of slash clearing.
5/Effects of culvert installation on road 443.3 above the "A" station.

measured at the "C" station is not just a function of stream discharge. The average amount of additional sediment reaching the "C" stations due to road pioneering was 40.65 lbs.

The clearing of right-of-way slash at the 18-1 stream crossing resulted in 1.56 lb of sediment reaching the "C" station. Slash clearing under normal conditions probably only has a slight effect on stream sediment concentrations. While only one crossing was monitored, visual observations at other crossings support this statement. Only slash removal from the channels or directly adjacent to the channels may potentially increase sediment concentrations.

Sediment measurements were made at the "B" stations at several crossings: 18-2, 18-3, 16-1, 12-1, 12-2, and 12-3. At crossings 18-2 and 18-3, measurements were made at the "B" stations; however, due to a plugged culvert, water and sediment was pumped over the road to the forest floor and contributed to the stream below the "B" station. Thus, these two stations will not be discussed.

The difference in quantities of sediment measured at the "B" and "C" stations, represent the change in storage of sediment in the channel reach between the two stations. Table 2 shows the amount of sediment deposited in this channel reach for those crossings where measurements were made at the "B" stations. The delivery ratio, the quantity of sediment measured at the "C" station divided by the quantity at the "B" station, ranged from 14.4 to 72.5%. There was no correlation between the delivery ratio and the magnitude of stream discharge.

The amount of sediment reaching the watershed mouths was measured during some pioneering activities that took place in watersheds 18, 16, and 12. Quantities of sediment at the mouths were compared with predicted quantities for the same stream discharge in an undisturbed condition. Any increases above the predicted quantity of sediment was attributed to the upstream pioneering activities. The difference between the quantities of sediment measured at the "B" and "C" stations and the quantity of sediment attributed to the pioneering activity at the mouth is shown in table 3. The percentage of sediment transported from the "C" stations to the mouth ranged from 0.0 to 10.9. Thus, a large percentage of the material is being deposited in the channel between the "C" station and the watershed mouth.

Peak sedimentation concentrations at the "C" stations during pioneering activities ranged from 2.4 to mg/1. Peak concentrations were not related to stream discharge. The mean peak concentration measured at ten "C" stations during pioneering was 2256 mg/1. During slash clearing at crossing 18-1 the peak concentration was 88.1 mg/1 and during road construction through a seep area above the "A" station at crossing 8-1, it was 3432.7 mg/1. Sediment concentrations upstream from the activities were usually less than 5 mg/1. Following the cessation of pioneering activities at a stream crossing, sediment concentrations decrease rapidly and in one to three hours have reached relatively low concentrations, but still greater concentrations than normal levels.

Table 2.--The difference in amounts of sediment measured at the "B" and "C" stations for selected crossings during pioneering activities.

Stream Crossing	Sediment "B" minus "C" lbs	Delivery Ratio "C" divided by "B" percent
16-1	+73.16[1/]	14.4
12-1	+10.05	34.6
12-3	+42.51	72.5

[1/] A positive value indicates deposition of sediment between the "B" and "C" stations.

Table 3.--The difference in amounts of sediment measured at the "B", and "C", and "Mouth" sampling stations for selected watersheds during pioneering activities.

Watershed	Sediment "B" minus "Mouth" lbs	Delivery Ratio "Mouth" divided by "B" %	Sediment "C" minus "Mouth" lbs	Delivery Ratio "Mouth divided by "C" %
18			+23.91	10.9
16	+85.48[1/]	0.0	+12.32	0.0
12	+162.07	4.7	+109.51	6.8

[1/] A positive value indicates deposition of sediment between the "B" and "C" stations.

Peak sedimentation concentrations at the mouths of the watersheds in response to pioneering were 26.5, 7.5, 9.8, and 3.9 mg/1 for watersheds 18, 16, 12, and 8, respectively. Their respective predicted suspended sediment concentration for the same stream discharge under undisturbed conditions were 4.6, 4.2, 0.9, and 1.3 mg/1. Thus, increases in sediment concentrations at the mouths were low, compared to those measured at the "C" stations. Concentrations decrease to near normal levels within five to ten hours after cessation of the pioneering activitiy.

PERMANENT CULVERT INSTALLATION

The sedimentation consequences of permanent culvert installation were monitored at numerous stream crossings during the road construction in 1978 and 1979. Table 4 shows the total amounts of sediment passing given sampling stations during and for a short time after culvert installation activities. The amount of sediment reaching live water and transported downstream was quite variable, ranging from 0.22 to 603.75 lbs at the "C" stations. The average amount of sediment reaching the "C" station for eight culvert installations was 82.96 lbs. The amount reaching the "C" stations was not directly related to stream discharge. Stream transport capacity, stream storage characteristics, and installation variables all influence the amount of sediment produced and transported. However, it should be noted that three sites, 16-1, 15-0, and 14-4, with very low stream discharges of 0.002, 0.005, and 0.0035 $ft^3 sec^{-1}$, respectively, transported very little sediment to the "C" stations.

At some of the stream crossings, measurements of total sediment were made at the "B" stations during culvert installation. Table 5 shows the differences in total sediment between the "B" and "C" stations. A positive value indicates deposition of sediment in the stream reach between the two stations. The percentage of sediment, measured at the "B" station, reaching the "C" station ranged from 3.1 to 14.0. At crossings 18-2, 18-3, and 14-1 there was more sediment reaching the "C" stations than was measured at the "B" stations; these are indicated by negative values in table 5. This represents a net scouring of the channel between the two stations. Stream discharge fluctuated greatly during culvert installation, especially at these three crossings. Higher stream discharges could transport sediment previously deposited in the channel during pioneering and/or rainstorms.

Sediment quantities transported to the watershed mouths were measured in watersheds 18, 16, 14, and 8 during the culvert installation impact period. Table 6 shows the difference in quantitites measured between the "C" station and the mouth and between the "B" station and the mouth. Predicted quantities of sediment at the mouth under undisturbed conditions were subtracted from the measured quantities to determine the quantity of sediment due to culvert installation. In these four instances there was deposition of material between the "C" station and the mouth. The net quantity of deposited sediment ranged from 0.75 to 440.60 lbs. Delivery ratio between the "C" stations and the mouth ranged from less than one percent to 56.0%.

Table 4.--The sedimentation consequences of permanent culvert installation at selected stream crossings in the Horse Creek watersheds.

Stream Crossing	Installation Start Time	Installation Start Date	Monitoring[1] Finish Time	Monitoring[1] Finish Date	Station A Sediment lb	Station A Discharge ft^3 sec	Station B Sediment lb	Station B Discharge ft^3 sec	Station C Sediment lb	Station C Discharge ft^3 sec	Mouth Sediment lb	Mouth Discharge ft^3 sec^{-1}
18-1	1300	7-09-78	1700	7-19-78	0.03	0.02	158.91	0.02	22.28	0.03		
18-2	0830	7-20-78	1730	7-20-78	0.11	0.04	9.50	0.04	603.75	0.06	215.39	0.85
18-3	0830	7-20-78	1730	7-20-78	0.55	0.01	99.35	0.03			(52.24)	
16-1[2/3/]	0800	7-25-78	1700	7-25-78	0.24	0.002	35.98	0.002	1.71	0.06	0.65	0.11
16-2[2/3/]	0800	7-25-78	1700	7-25-78	1.84	0.04	19.73	0.04			(0.96)	
16-1[2/]	0750	7-26-78	1100	7-26-78	0.01	0.002	1.84	0.002	0.22	0.06		
16-2	0750	7-26-78	1100	7-26-78	0.06	0.04	0.85	0.04				
15-0	1220	7-25-78	1700	7-25-78	0.01	0.01	193.26	0.01	8.12	0.01		
15-1	0830	7-13-79	1315	7-13-79	0.01	0.005			0.93	0.005		
14-1	0815	7-17-79	1015	7-18-79	0.29	0.02	28.11	0.03	185.41	0.03		
14-2	1300	7-17-79	1400	7-18-79	0.14	0.01			27.81	0.02	2.97	0.09
14-3	1300	7-17-79	1400	7-18-79	0.06	0.004					(0.58)	
14-4	1400	7-18-79	1200	7-18-79	0.09	0.004			3.56	0.004		
8-1	0815	8-1-78	1200	8-2-78					45.90	0.02	0.48	0.42
8-2	1030	8-29-78	2000	8-29-78	0.08	0.006	0.71	0.006	12.89	0.02		
8-3[2/]	1030	8-29-78	2000	8-29-78	0.06	0.01						

1/The duration of sampling at the "A", "B", and "C" stations. The duration of sampling was considerably longer at the mouth.
2/Indicates the crossing at which the culvert was being installed.
3/Indicates a crossing at which the site was dewatered.

Table 5.--The difference in amounts of sediment measured at the "B" and "C" station for selected crossings during culvert installation.

Stream Crossing	Sediment "B" minus "C" lbs[1]	Delivery Ratio "C" divided by "B" %
18-1	+136.63	14.0
18-2,3	-494.90	-
16-1,2[2]	+ 54.00	3.1
16-1,2[3]	+ 2.47	8.2
15-0	+185.14	4.2
14-1	-157.30	-

[1] A positive value indicates deposition of sediment in the channel reach from the "B" to the "C" station. A negative value indicates channel scour.

[2] Installation of a culvert at crossing 16-2.

[3] Installation of a culvert at crossing 16-1.

Table 6.--The difference in amounts of sediment measured at the "B" and "C" stations and the watershed mouths during culvert installations.

Stream Crossing	Sediment "B" minus "Mouth" lbs[1]	Delivery Ratio "Mouth" divided by "B" %	Sediment "C" minus "Mouth" lbs[1]	Delivery Ratio "Mouth divided by "C" %
18-2,3[2]	-54.30		+440.60	27.0
16-1,2[3]	+54.75	1.7	+ 0.75	56.0
14-1,2,3,4			+214.39	1.1
8-1			+ 45.63	0.6

[1] A positive value indicates deposition of sediment in the channel and a negative value indicates channel scour.

[2] Culvert being installed at crossing 16-2.

Peak concentrations of sediment at the "C" stations during culvert installation were highly variable and ranged from 5.3 to 39,243 mg/1. The 5.3 mg/1 was measured during installation of a culvert at crossing 16-1. The stream discharge at this crossing was only 0.002 $ft^3 sec^{-1}$, which probably was partially responsible for the low concentrations of sediment measured at the "C" station. This was also evident at crossing 14-4 which had a peak sediment concentration of 794.2 mg/1 and a stream discharge of only 0.0035 $ft^3 sec^{-1}$. The mean peak sediment concentration measured at ten "C" stations during culvert installation was 5924.8 mg/1. Typically, the concentrations decrease very rapidly following cessation of the installation work and in several hours had declined to low concentrations, but still greater than undisturbed concentrations.

Peak concentrations of sediment at the watershed mouths ranged from 2.6 mg/1, essentially no noticeable effect, to 134.9 mg/1. The mean peak concentration for seven installations was 22.9 mg/1. Concentrations measured at the watershed mouths are small, compared to those at the "C" stations. Any measurable increases in sediment concentrations were relatively short lived, usually less than five hours, at which time concentrations are back down to normal or slightly above normal levels.

SUMMARY AND CONCLUSIONS

During pioneering and culvert installation activities at the stream crossings in Horse Creek the sediment concentrations, total sediment contributed, and delivery of sediment downstream were highly variable. On the average, 41 lbs and 83 lbs of road derived sediment were measured at the "C" stations during pioneering and culvert installation, respectively. Comparisons between the total sediment measured at the "B" and "C" stations indicate that much of the sediment contributed at the "B" station adds to channel storage in the "B" to "C" reach of stream. During pioneering, an average of 41% (n=3) of the sediment measured at the "B" station was transported to the "C" station. During culvert installation, sediment was deposited in the "B" to "C" reach of channel in four instances. In these four streams, only 7.4% of the sediment measured at the "B" station was transported to the "C" station. In two instances there was a scouring of the channel, or a negative net change in channel storage, between the "B" and "C" stations.

The total sediment measured at the mouths of these watersheds during construction activities amounted to only a small fraction of the total sediment measured at the "B" or "C" stations. Total sediment that could be attributed to road construction ranged from 0 to 8 lbs during pioneering and 0 to 163 lbs during culvert installation. The percentage of sediment transported from the "C" stations to the mouths ranged from 0 to 11% and 1 to 56% during pioneering and culvert installation, respectively. These data indicate a net increase in channel storage of sediment between the "C" and mouth staions during road construction.

The sedimentation consequences of road construction must be considered in both time and space. In Horse Creek the concentrations and total amounts of sediment decreased rapidly as sampling moved downstream. It is doubtful if any of the road construction activities would have measurably altered sediment concentrations at the mouth of the Main Fork. These data suggest a loading of the channels with sediment. Subsequent hydrologic events may flush this sediment downstream resulting in a delayed effect of road construction.

SECTION 7

ONSITE EROSION

ONSITE EROSION

INTRODUCTION

Erosion of forest roads has been shown to be an important source of sediment to streams. Both surface erosion and mass wasting occur on forest roads and both of these processes have occurred on the roads in Horse Creek.

Surface erosion has occurred as sheet erosion, rill erosion, and dry ravelling. Sheet erosion is caused predominantly by raindrop impact which dislodges mineral particles and transports them via raindrop splash. Freeze-thaw processes during the spring may also dislodge particles. Rill erosion has occurred on the fill slopes, along the edge of the subgrade just above the fill slopes, and in the ditches. It is caused by the concentration of running water which exerts enough sheer stress to dislodge mineral particles and transport them. Transport distances over the forest floor below rills in the fill slopes have exceeded 500 feet. Dry ravelling is caused by the force of gravity on individual mineral particles or clumps of particles. This process occurs on the cut slopes during the dry summer months.

Mass wasting as small slump-earthflows has occurred on both the cut and fill slopes in Horse Creek. Slumping is most evident in the early spring during snomelt. Saturated or near saturated conditions of the cut and fill material are believed to be the primary cause of this process.

Previous studies have shown a marked decrease in surface erosion over time. This is due to a combination of revegetation of the cut and fill slopes and the armouring of the surface. This trend has been seen on some fill slopes in Horse Creek. Mass wasting events may not follow this same time trend.

PURPOSE

The purpose of this section of the report is to provide a quantitative assessment of surface erosion of cut and fill slopes on the Horse Creek roads, from construction to the summer of 1980. The data are expressed as volumes of eroded material for individual roads or road segments and also eroded volumes for different height categories of cut and fill slopes.

These data will eventually be used to:

1. Evaluate differences between slope stabilization treatment.

2. Partition the relative sediment contributions, to the stream, by source.

3. Determine quantitative models relating erosion volumes or rates with time and/or precipitation.

4. Statistical evaluation of differences in erosion between height categories.

5. Predict volumes of erosion that potentially could contribute to the stream sediment at each "C" station and watershed mouth.

FILL SLOPE EROSION

Road and Fill Slope Characteristics

The amount of fill slope erosion occurring on a section of road may be influenced by many site factors. In Horse Creek, the type of topography across which the road was constructed and the design standards for the road determined the areal extent of fill slopes and the height of the fill slopes. Road surfacing and road surface drainage also influences the magnitude of surface erosion as well as the type of stabilization treatments of the fill slopes.

Table 1 gives a summary of some of the important road characteristics for the various Horse Creek roads that may influence surface erosion of the fills. The amount of areal disturbance of fill slopes, expressed in mi^2/mi, ranged from 0.0028 to 0.0058. Standard II roads, which were designed to fit the topography to minimize cut and fill slopes, always had a disturbance equal to or greater than Standard I roads. Thus, the type of topography largely controlled the size of the fill slopes. Table 1 shows the percentage of road length in various fill slope height categories. The percentage of road length with category 4 fill slopes, greater than 30 feet in vertical height, was not related to the road standard. For both standards, fill slopes had a design slope of 1 1/2:1.

Fill slope stabilization treatments on Horse Creek roads were: no treatment, seeded, seeded plus hydromulched, and seeded plus a straw mulch with an asphalt tack. Until the seed germinates the mulch affords some fill slope protection, at least from raindrop splash erosion. An important consideration is the length of time between road construction and fill slope treatment. Summer thunderstorms could have a much more damaging effect on the fill slopes if mulching is not done until the end of the road construction season.

Road surfacing material and the type of road surface drainage may also affect the magnitude of fill slope erosion. The Horse Creek roads typically had a flat subgrade with a ditch and relief culvert drainage system. Road surface treatments were: a gravel surface, an asphalt surface, and a native soil surface. The amount of overland runoff generated on the road surface during rain or snowmelt events and the rate at which it is delivered to the ditch or fill slope may be controlled by surface treatment and road design.

Table 1.--Road and fill slope characteristics for the Horse Creek roads.

Road	Station	Fill slope disturbance mi^2/mi [1]	Fill slope Treatment [2]	Road Surface [3]	Road Standard	Percentage of road length in each height category [4] 1	2	3	4	5
9704	0+00-79+05	0.0029	H	G	I	61.0	31.4	6.6	1.0	0.0
9704	79+05-129+37	0.0032	S/A	A	II	44.8	29.0	9.2	5.7	11.3
9704	129+37-194+00	0.0044	None	N	I	16.8	17.3	19.2	9.9	36.7
9704	194+00-238+70	0.0059	S	N	II	17.1	33.5	30.0	17.7	17.2
9708	0+00-73+15	0.0031	S/A	G	II	44.7	34.0	10.7	1.8	8.8
9709	0+00-64+48	0.0036	S/A	G	II	41.8	21.1	13.2	6.1	10.8

[1] Horizontal area of fill slopes per mile of road, excluding sections of road with no fill slopes.

[2] H=hydromulch plus seed, S/A=straw mulch with an asphalt tack plus seed, S=seed (no mulch).

[3] G=gravel, A=asphalt, N=native soil.

[4] Categories 1, 2, 3, 4, and 5 are respectively 0-10, 10-20, 20-30, greater than 30 vertical feet, and no fill slopes.

The soil texture of the fills will also influence the surface erosion process. The fill slope material on Horse Creek roads on the average is composed of 12.0% gravel, 69.4% sand, and 18.6% silt and clay. The texture would be classified as a silty sand.

METHODS

Fill slope erosion was measured using four-foot long troughs located at the toe of the slope. The troughs are constructed of galvanized sheet metal with wooden bracing. The troughs are six inches deep by six inches wide and capable of holding one cubic foot of material. To install the troughs the duff and liter were removed from the site and a place was leveled for the trough. Troughs were installed so the upper edge of the trough was flush with the ground level and immediately below the toe of the fill slope. Troughs were anchored in place with wooden stakes.

The troughs were installed as soon as possible following road construction. Each fall, prior to snow cover, and each spring, shortly after the disappearance of the snowpack, volumes of eroded material were removed from each trough and measured. Eroded volumes were also measured sporadically throughout the summer following major rain events.

The installation sites for the troughs were chosen so that measurements of erosion were made on various heights of fill slopes. Fill slopes were stratified by height into four categories; 0-10 feet (Category 1), 10-20 feet (Category 2), 20-30 feet (Category 3), and greater than 30 feet (Category 4). The first trap was located randomly in the first 100 feet of fill slope in a given category. The remaining troughs in each category were located at fixed intervals within the height category. The total length of fill slope that received troughs in each category was approximately one percent. The number of troughs in each height category for each road is shown in table 2.

Sampling intensity of the fill slopes was intentionally small, usually less than one percent. It was felt that intensive sampling may trap too large a percentage of the eroded material and possibly influence stream sedimentation.

ANALYSIS AND RESULTS

Table 3 shows the total and seasonal fill slope erosion for the Horse Creek roads. These values are weighted averages, weighting fill slope erosion in each height category by the length of road in each category. Total erosion ranges from 12.15 to 53.06 ft^3/100 ft of road for roads constructed in 1978 and ranges from 33.10 to 59.71 ft^3/100 ft of road for roads constructed in 1979. A small sampling intensity for a highly variable process is responsible for much of this variation. However, the date of road completion and subsequent trough installation also influenced these volumes. For example, in the summer of 1978, road 9704, stations 0+00 to 79+05, road 9708, and road 9709 had erosion volumes of 31.23, 6.58, and 0.00 ft^3/100 ft of road, respectively.

Table 2.--Number of fill slope troughs by height category for the Horse Creek roads.

Road	Station	Height Category 1	2	3	4	Total
9704	0+00-79+05	5	3	1	0	9
9704	79+05-129+37	6	4	1	0	11
9704	129+37-194+00	10	4	3	2	19
9704	194+00-238+70	1	3	4	3	11
9708	0+00-73+15	4	5	3	0	12
9709	0+00-64+48	5	3	2	2	12
	Total	31	22	14	7	74

Table 3.--Total and seasonal fill slope erosion (weighted average) for the Horse Creek roads.

Road	Station	1978 Summer	1978/79 Winter	1979 Summer	1979/80 Winter	1980 Summer	Total
		----------ft^3/100 ft on road----------					
9704	0+00-79+05	31.23	2.11	9.12	2.13	8.47	53.06
9708	0+00-73+15	6.58	1.20	1.00	2.97	0.40	12.15
9709	0+00-64+48	0.00	4.44	5.30	15.28	13.41	38.43
9704	79+05-129+37			16.17	13.18	8.92	38.27
9704	129+37-194+00			7.26	16.24	36.21	59.71
9704	194+00-238+70			1.09	16.49	15.52	33.10

Installation of troughs on 9708 and 9709 were 2 and 6 weeks later, respectively, than on 9704. Troughs on road 9704 trapped eroded material during rain events totalling 1.1 and 2.8 inches before trough installation on roads 9708 or 9709.

Typically, rainstorms during the first summer, just after construction, caused the most fill erosion. For example, 56% of the cummulative erosion for 2 years on road 9704, stations 0+00 to 79+05, occurred from mid August through October, 1978. The first large convective storm, 0.89 inches of rain, produced approximately 8.32 ft^3/100 ft of erosion on this road. The amount of erosion during the first summer was dependent on the construction date of the road. As previously mentioned, those roads which were completed later in the summer, had smaller quantities of fill erosion.

During subsequent summers, the amount of fill erosion is usually less than during the first summer. This is attributed to vegetation establishment on the slopes and armouring of the slopes. For example, fill slope erosion on road 9704, stations 0+00 to 79+05, during the second and third summers was only 29% and 27% of the amount of erosion during the first summer. Not all of the road fills behaved in this manner. For example, road 9709 fills had increasing amounts of erosion for three successive summers.

Winter erosion, erosion of the fill slopes during spring snowmelt, was quite variable. Fill erosion during this period of time is a combination of surface and mass erosion. Slumping of the fill slopes was common during saturated conditions in the spring. For roads constructed in 1978, winter surface erosion accounted for 8 to 51% of the total fill erosion and for roads constructed in 1979, it accounted for 27 to 50% of total fill erosion. There was a tendency for greater winter erosion on road segments with larger areal disturbance of fills.

Summer erosion usually accounted for the majority of fill erosion, especially on those roads with the smaller areal disturbance in fills. However, statistical analysis of the data did not show a significant difference between winter and summer erosion volumes.

The greatest cummulative erosion has been measured on road 9704, stations 129+37 to 194+00. Fill slopes on this road section did not receive any type of stabilization treatment. However, we feel that with only one year of fill erosion data on those roads constructed in 1979, it is premature to make any definitive statements about treatment differences.

Table 4 shows the fill slope erosion by height category for each road or road segment. Differences in erosion between height categories were tested for significance using a t-test. There were no significant differences. However, it may be difficult to detect real differences since the number of troughs was small and the variation between erosion measured at the different troughs was large. There are trends in the data that I believe are real. Hopefully, additional fill slope erosion data from the rill surveys will substantiate some of these observations.

Table 4.--Total fill slope erosion by height category as of mid summer 1980 for the Horse Creek roads.

Road	Station	Height Category 1	2	3	4	Weighted averages	Installation date
		------ft^3/100 ft of road-------					
9704	0+00-79+05	39.11	78.91	63.50	-	53.06	8-10,11-78
9704	79+05-129+37	9.76	34.90	211.60	-	38.27	8-29-79
9704	129+37-194+00	16.43	73.57	52.41	150.13	59.71	10-2-79
9704	194+00-238+70	5.70	24.84	42.33	60.68	33.10	10-2-79
9708	0+00-73+15	0.62	18.45	42.46	-	12.15	8-31-78
9709	0+00-64+48	21.69	38.84	52.50	120.00	38.43	9-27-78

Fill slope erosion increases as the fill slope height increases (table 4). This was evident on four of the six road segments. Averaging all roads together, fill erosion in height categories 2, 3, and 4 was greater than erosion in category 1 by factors of 6.9, 17.0, and 19.5, respectively.

MODELING

For roads constructed in 1978, two years of fill slope erosion data were available for model construction. The plots of cummulative erosion versus the number of days since trough installation or versus the number of inches of precipitation since installation, appeared to have a definable curvilinear relationship.

Several models were tested and the best model describing this relationship was:

$$Y = \beta_0 + \beta_1 X + \beta_2 \ln X + \varepsilon$$

where:

Y = cummulative erosion, $ft^3/100$ ft of road,

X = number of days since trough installation or number of inches of precipitation since trough installation,

ε = error

$\beta_0, \beta_1, \beta_2$ = regression coefficients.

Tables 5 and 6 show the resulting models for roads 9704 and 9708. The coefficient of determination was usually greater than 0.90 for the models for roads 9704 and 9708. Models have not been developed for road 9709 and will not be developed until after three years of data have been collected. Erosion of the fills has not decreased over time and until these fills stabilize, cummulative erosion models will not be developed.

Figures 1 and 2 show the fill slope erosion data for all three roads and the models developed for roads 9704 and 9708, for predicting weighted average erosion. Figures 3 and 4 show the models predicting cummulative fill erosion over time for the various fill slope height categories on roads 9704 and 9708, respectively.

Table 5.--Regression coefficients and statistical information for the fill slope erosion model: $Y = \beta_0 + \beta_1 X + \beta_2 \ln X$, where X equals the number of days since trough installation and $\hat{Y}$ equals cummulative erosion in $ft^3/100$ ft of road.

Road	Station	$\hat{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	R^2	F value	Probability of a greater F
9704	0+00-79+05	Wt.Ave. [1/]	0.2343	0.0131	5.9061	0.94	71	0.0001
		HC1 [2/]	-0.2583	-0.0010	5.6591	0.90	43	0.0001
		HC2	-2.9728	0.0261	8.5957	0.96	102	0.0001
		HC3 [3/]	23.4265	0.0861	-5.1399	0.87	30	0.0001
9708	0+00-73+15	Wt.Ave.	1.3489	0.0073	0.8309	0.96	44	0.0019
		HC1	0.3510	0.0015	-0.1315	0.89	16	0.0123
		HC2	-1.5117	0.0178	0.9397	0.96	43	0.0020
		HC3	15.8330	0.0103	2.8697	0.92	22	0.0071

[1/] Wt.Ave. = weighted average erosion

[2/] HC = height category

[3/] This model is based on data from only one fill slope trough.

Table 6.--Regression coefficients and statistical information for the fill slope erosion model: $Y = \beta_0 + \beta_1 X + \beta_2 \ln X$, where X equals the number of inches of precipitation since trough installation and $\hat{Y}$ equals cummulative erosion in $ft^3/100$ ft of road.

Road	Station	$\hat{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	Correlation coefficient	F value	Probability of a greater F
9704	0+00-79+05	Wt.Ave. 1/	14.5490	0.0733	6.4896	0.91	48	0.0001
		HC1 2/	13.4666	-0.0314	5.8019	0.86	28	0.0001
		HC2	17.5470	0.1290	10.1747	0.94	70	0.0001
		HC3 3/	12.5002	0.8324	-5.2759	0.91	43	0.0001
9708	0+00-73+15	Wt.Ave.	3.6908	0.0655	0.7726	0.93	25	0.0054
		HC1	0.0722	0.0138	-0.1351	0.94	32	0.0035
		HC2	1.3482	0.1585	0.9133	0.94	33	0.0032
		HC3	23.8797	0.1068	2.3520	0.86	12	0.0206

1/ Wt.Ave. = weighted average

2/ HC = height category

3/ This model is based on data from only one fill slope trough.

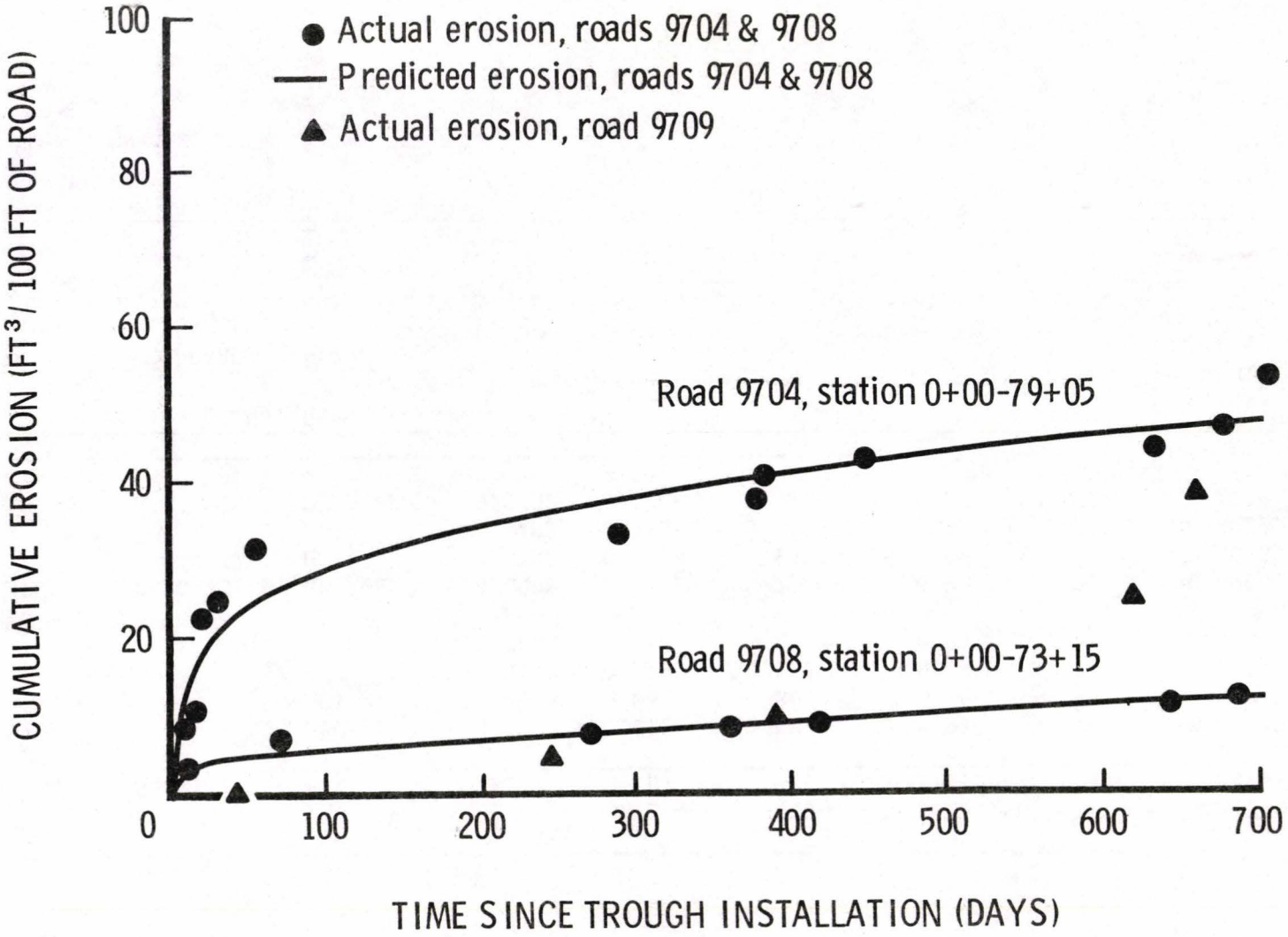

Figure 1.--Actual and predicted cumulative average fill slope erosion over time for Horse Creek roads constructed in 1978.

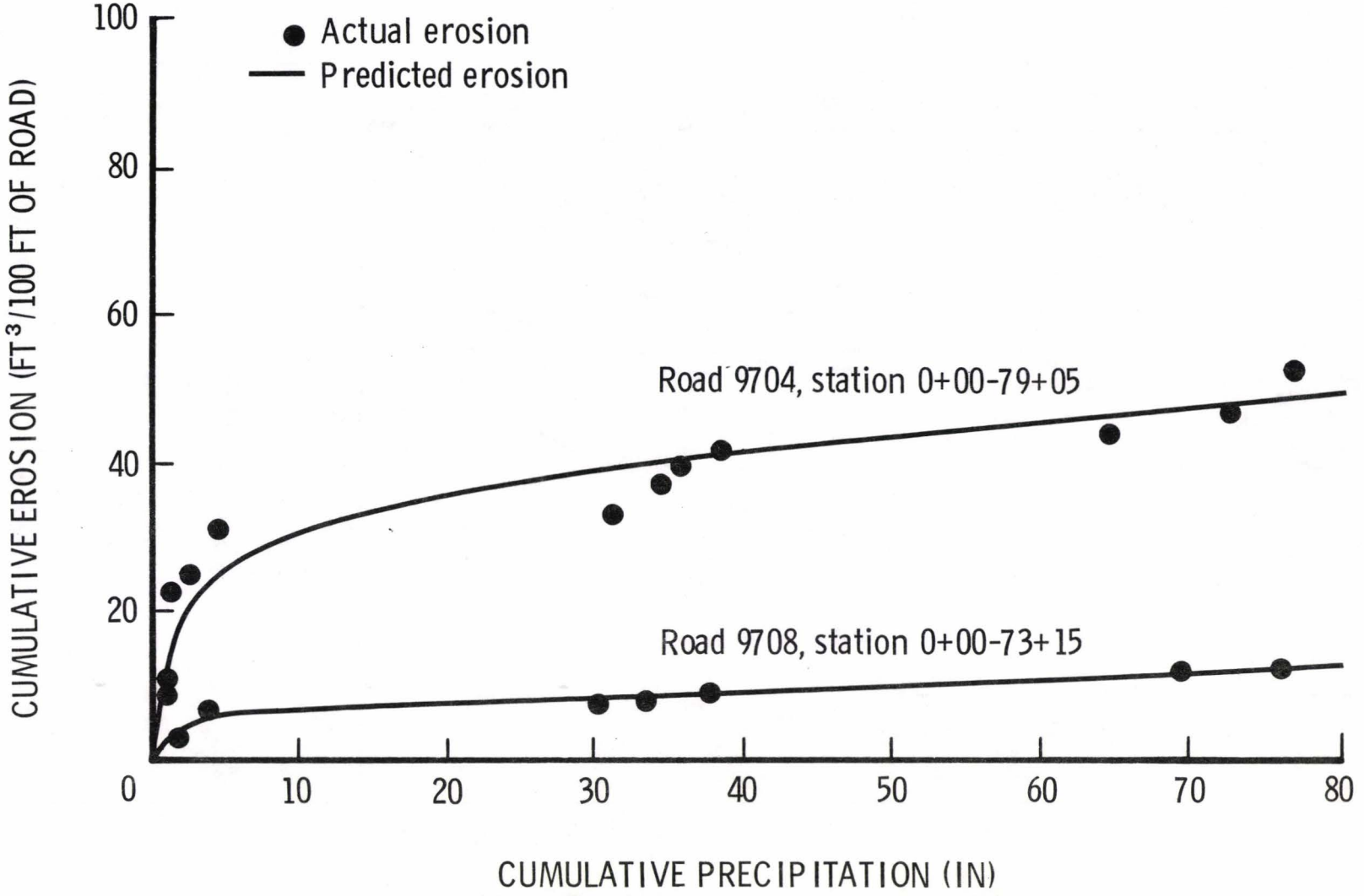

Figure 2.--Actual and predicted cumulative average fill slope erosion over cumulative precipitation for Horse Creek roads 9704 and 9708.

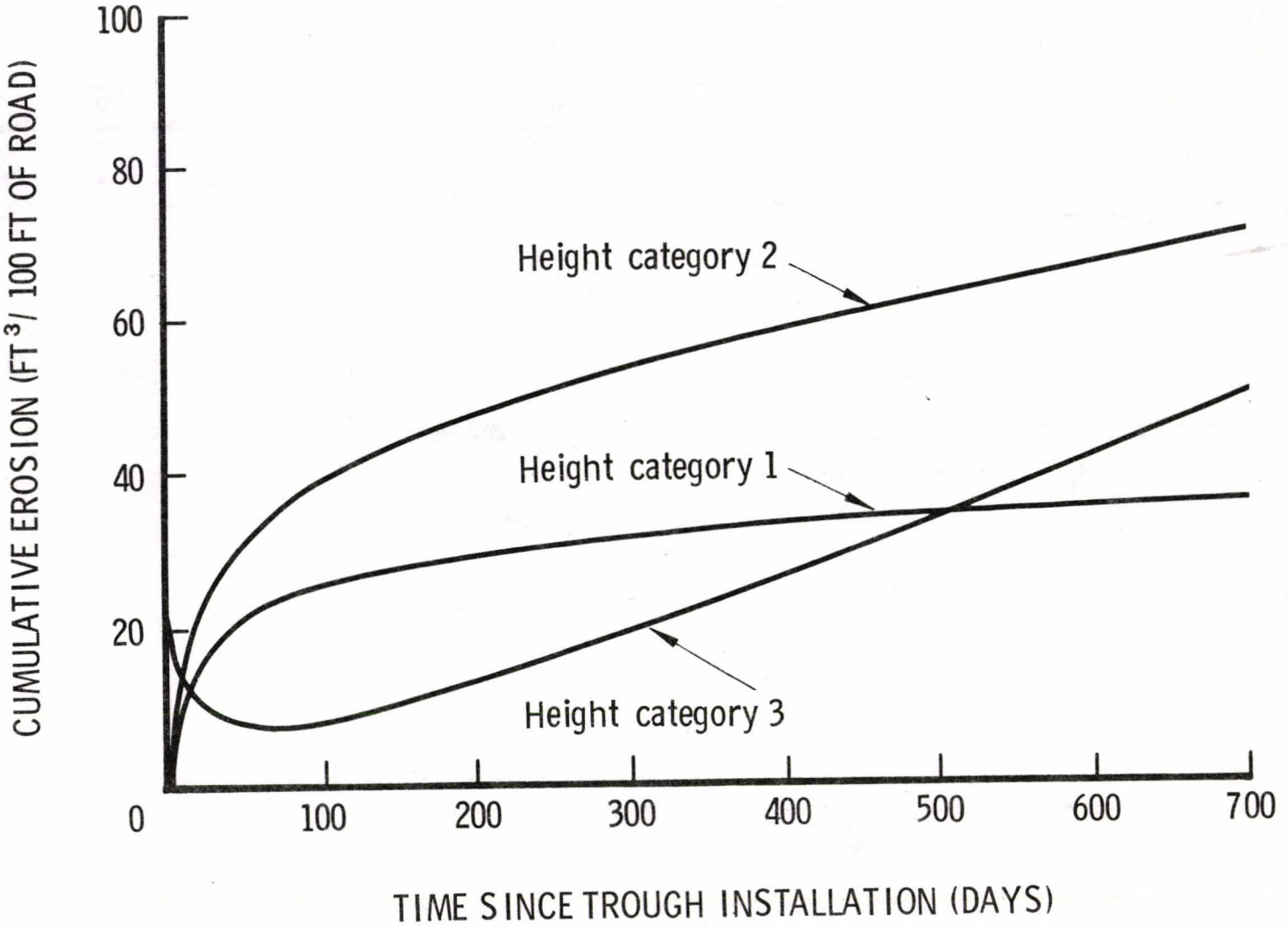

Figure 3.--Predicted cumulative average fill slope erosion over time by fill slope height category for Horse Creek road 9704, stations 0+00-79+05.

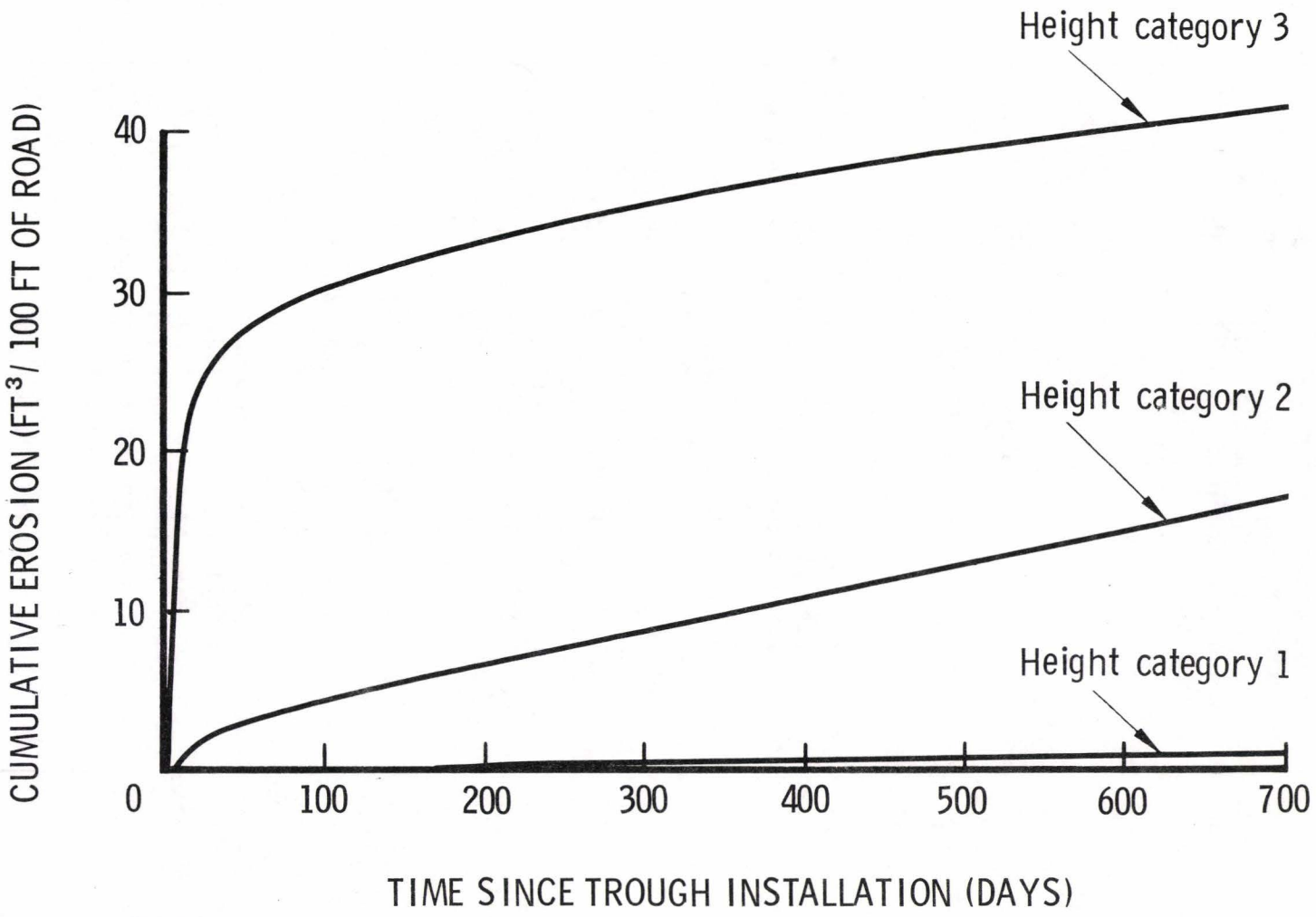

Figure 4.--Predicted cumulative average fill slope erosion over time by fill slope height category for Horse Creek road 9708, stations 0+00-73+15.

Plots and models of erosion over time showed that erosion volumes were greatest during the first summer and decreased over time on roads 9704 and 9708, constructed in 1978. However, the models predicting cummulative erosion volumes as a function of time ignore the driving force for erosion, rainfall. Thus, models were developed to predict the rates of erosion per unit rainfall over time. These models took the form of an allometric curve:

$$\ln Y = \beta_0 + \beta_1 \ln X + \varepsilon$$

where:

Y = erosion rate per unit of rainfall, ft^3/100 ft/day/inch,

X = time since trough installation, days, and

ε = error.

In developing the models, the data for the snowmelt period was excluded since the precipitation during that time period is in the form of snow. Snowmelt erosion rates will be discussed separately.

Table 7 and figures 5, 6, and 7 show the models for the two roads for the weighted average erosion rate and for the erosion rates by height category of fill slope. The models for the weighted average erosion fit the data very good as shown by the coefficients of determination. The models for each height class fit the data reasonably good, except for height class 1 on road 9708. The mean of the natural logarithm of the erosion rate data for height class 1 was -9.96, which is equal to 0.000047 ft^3/100 ft/day/inch of precipitation. Models for 9709 will not be developed until an additional year of data is collected on fill slope erosion.

These erosion rate models cannot be used to predict fill erosion rates during snowmelt runoff. Volumes of fill slope erosion for the winter period are shown in table 8 for the weighted average values. Winter fill slope erosion rates are quite small compared to rates during the summer months (ranging from 0.043 to 0.475 ft^3/100ft/week for the weighted average values). Winter erosion rates did not always increase as the height of the fill slope increased. However, winter fill slope erosion rates on road 9709 were an order of magnitude greater than those on roads 9704 or 9708. Road 9709 had the largest areal disturbance of fill slopes, 0.0036 mi^2/mi, and larger percentages of fill slopes in height categories 3 and 4, 13.2 and 6.1%, respectively.

Table 7.--Regression coefficients and statistical information for the fill slope erosion rate curves. The model is of the form $\ln Y = \hat{\beta}_0 + \hat{\beta}_1 \ln X + \varepsilon$, where X = number of days since trough installation and Y = erosion rate, ft^3/100 ft/day/inch of precipitation.

Road	Station	Erosion Rate $\hat{Y}$	Regression Coefficients $\hat{\beta}_0$	$\hat{\beta}_1$	R^2	F value	Probability of a greater F
9704	0+00-79+05	Wt.Ave.[1/]	3.5047	-1.5619	0.95	121	0.0001
		HC1 [3/]	4.0009	-1.8261	0.90	63	0.0001
		HC2	3.6424	-1.4879	0.94	115	0.0001
		HC3	0.2402	-0.9645	0.67	12	0.0134
9708	0+00-73+15	Wt.Ave.	3.4358	-1.9026	0.96	94	0.0023
		HC1	mean = 9.9598 st. dev. = 0.2843				
		HC2	-0.9725	-0.9792	0.70	7	0.0800
		HC3	6.8211	-2.4410	0.96	80	0.0029
9709	0+00-64+48	----models not developed---					

[1/] Wt.Ave. = weighted average erosion rate

[2/] HC = height category

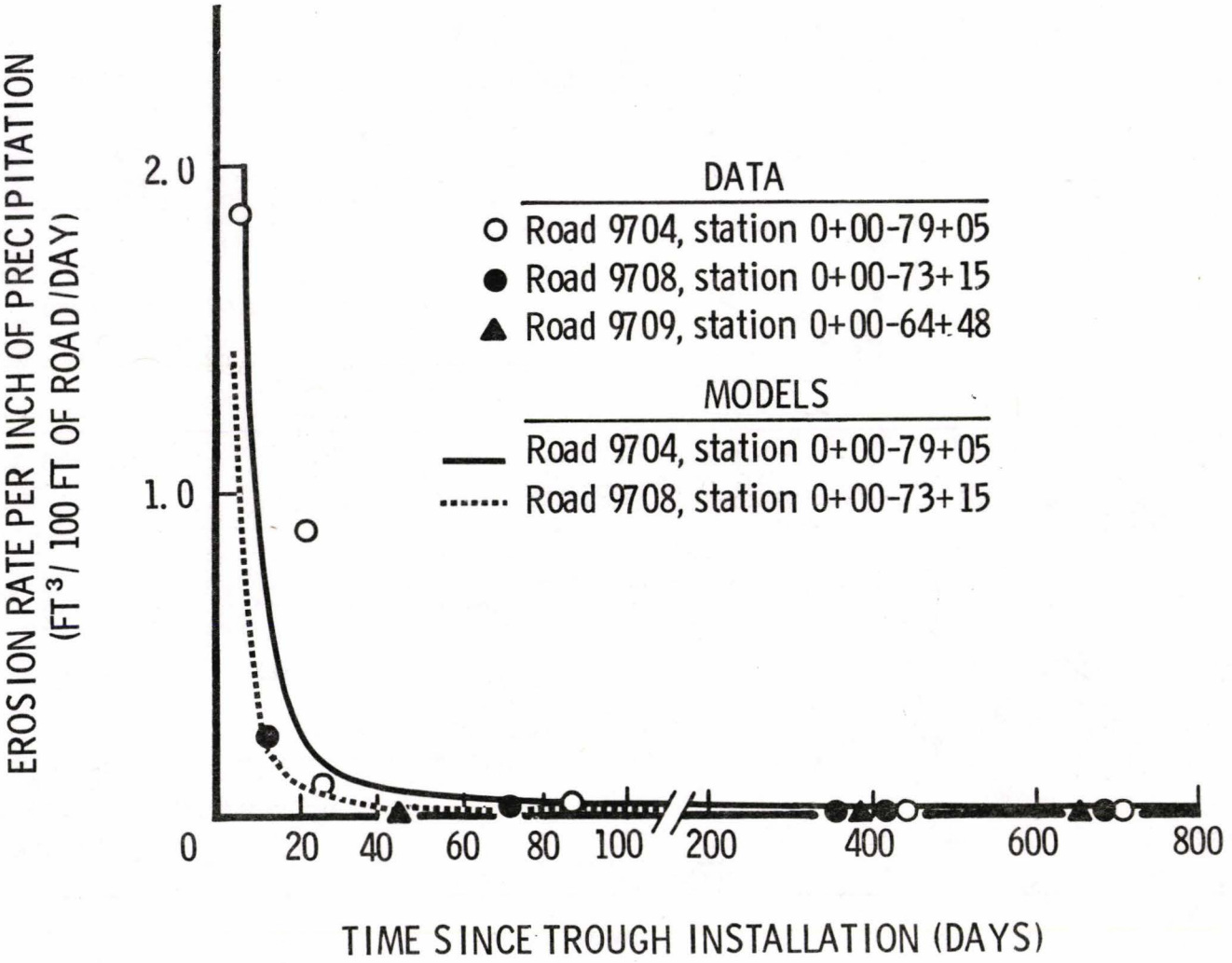

Figure 5.--Predicted and actual average fill slope erosion rates per inch of precipitation over time for the Horse Creek roads constructed in 1978.

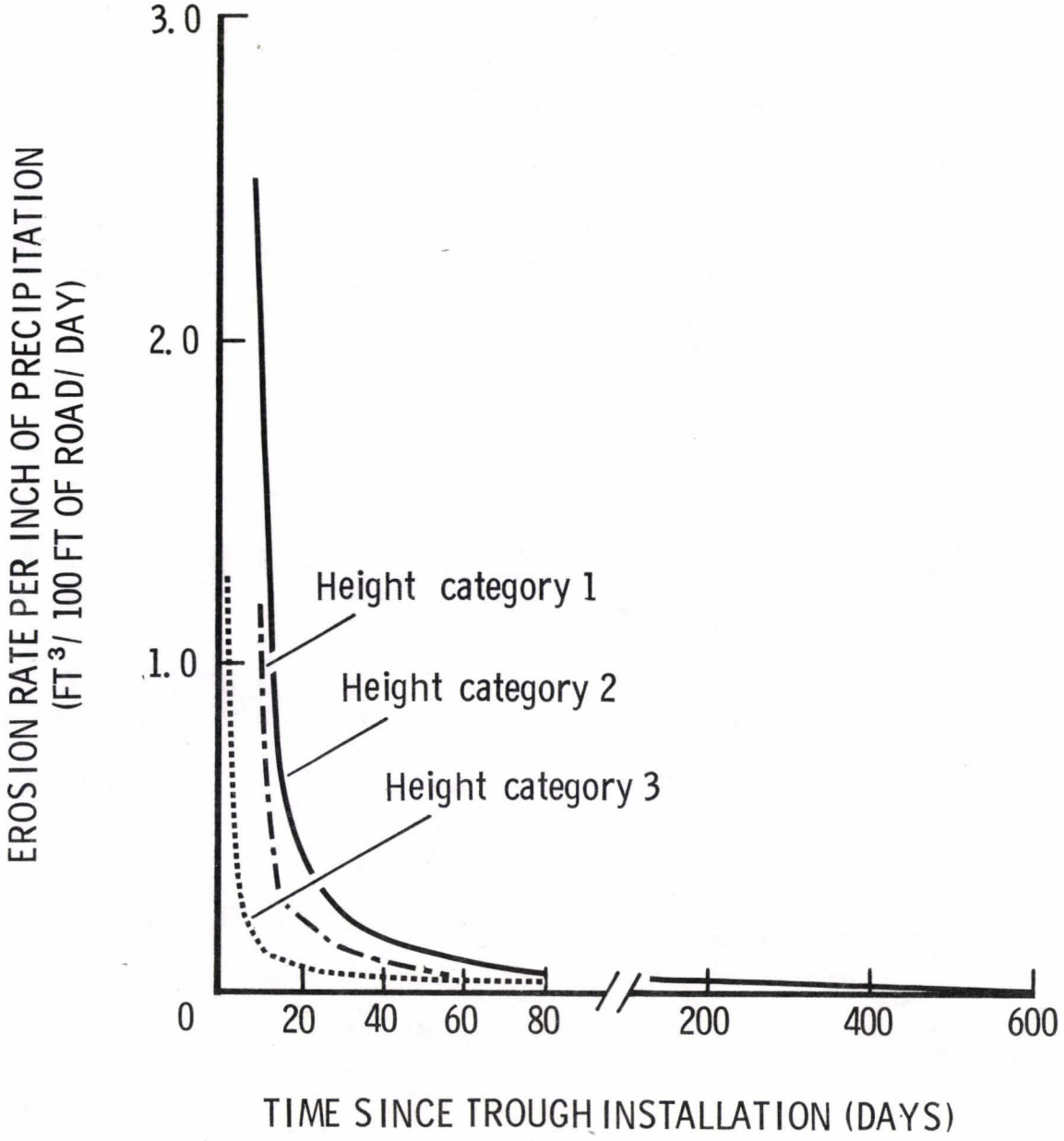

Figure 6.--Predicted fill slope erosion rates per inch of precipitation over time for the three fill slope height categories on Horse Creek road 9704, stations 0+00-79+05.

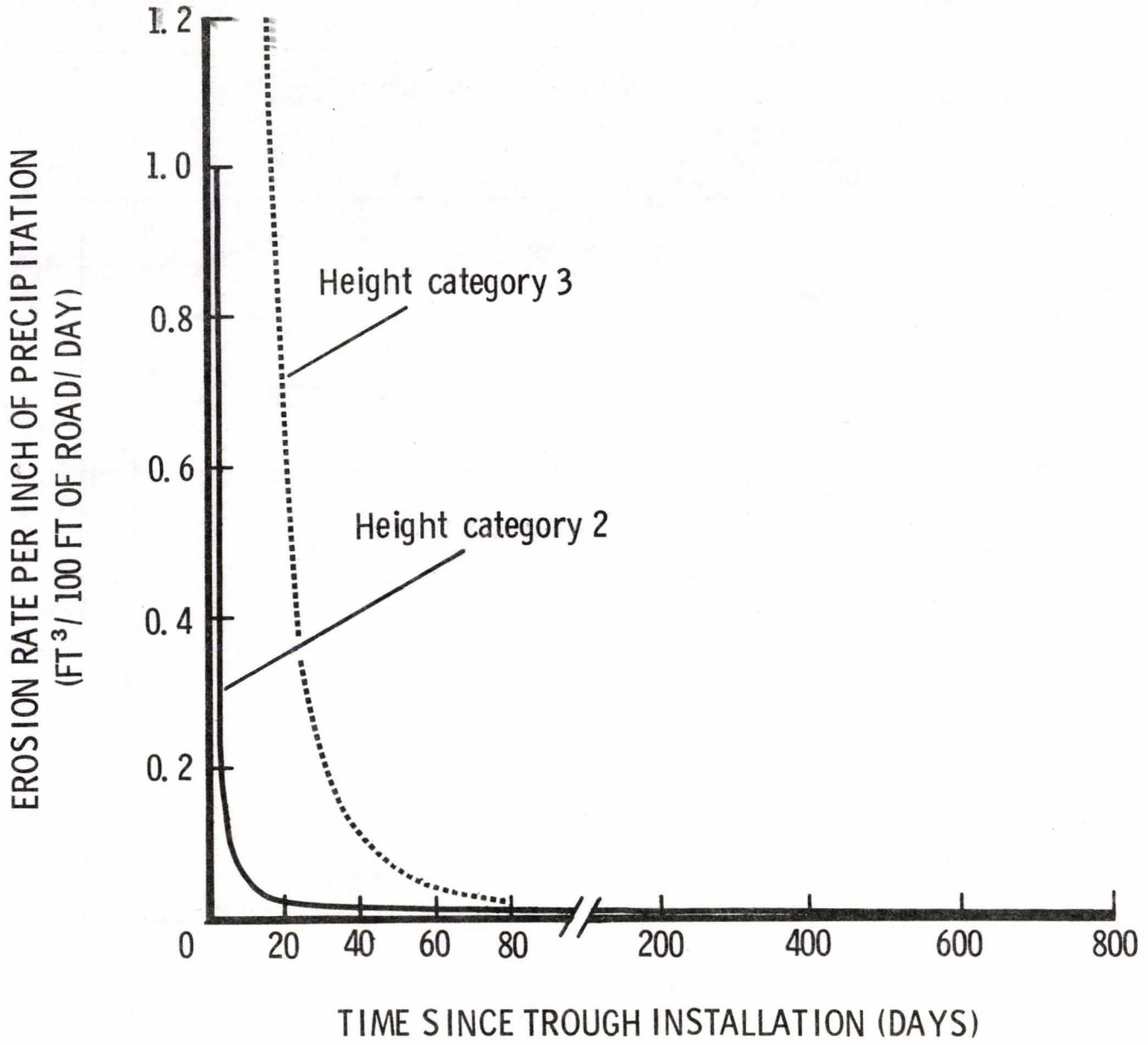

Figure 7.--Predicted fill slope erosion rates per inch of precipitation over time for fill slope height categories 2 and 3 on Horse Creek road 9708, stations 0+00-73+15.

Table 8.--Winter fill slope erosion rates on those Horse Creek roads constructed in 1978.

Road	Station	Fill slope Height category	1978-79 ft^3/100 ft of road/week	1979-80
9704	0+00-79+05	1	0.008	0.100
		2	0.175	0.015
		3	0.050	0.450
		Wt.Ave.[1/]	0.075	0.075
9708	0+00-73+15	1	0.000	0.008
		2	0.095	0.160
		3	0.043	0.210
		Wt.Ave.	0.043	0.093
9709	0+00-64+48	1	0.325	0.193
		2	0.000	0.555
		3	0.000	0.813
		4	0.000	1.150
		Wt.Ave.	0.150	0.475

[1/] Wt.Ave. = weighted average erosion

CUT SLOPE EROSION

Methods

Cut slope erosion was measured using four foot long traps located at the base of the cut slopes. These traps were constructed of 18 gauge flattened expanded metal with wooden bracing. The expanded metal was lined with a 200 micron polyethylene mesh which traps mineral particles, but allows water to pass through. A planting bar was used to incise the cut slope and the trap was installed four inches into the incision. The trap was anchored in place with 1/2 inch diameter reinforcing rod. At several locations approximately 10 inches above the trap, spikes were driven into the cut slope so that their heads were flush with the soil surface. This established the baseline surface prior to deposition of eroded material in the trap.

The cut slope traps were installed as soon as possible following road construction. Each fall, just before snow cover, and each spring, just after the disappearance of the snowpack, eroded material was removed from the traps and the volumes measured. Material was removed back to the baseline surface. In addition, volumes of cut slope erosion were measured sporatically throughout the summer following some of the major rainfall events.

In selecting the trap installation sites, the cut slopes were stratified by vertical height into four categories: 0 to 10 feet (category 1), 10 to 20 feet (category 2), 20 to 30 feet (category 3), and greater than 30 feet (category 4). The first trap was located randomly in the first 100 feet of road in a given height category. The remaining traps in each category were located at fixed intervals of distance. The amount of cut slope sampled within a height category was approxiamtely one percent of the total length of the cut slope. The number of cut slope traps by height category for each road is shown in table 9. The intensity of sampling was intentionally small. It was considered desirable to minimize the trapping of material that could potentially enter a stream.

Road and Cut Slope Characteristics

Table 10 shows some of the road and cut slope characteristics for the Horse Creek roads that may influence cut slope erosion. The magnitude of cut slope erosion may be influenced by the amount of area exposed as cut slopes and the vertical heights of the cuts. These two road characteristics are a function of the specific road design standards and the type of topography upon which the road is constructed. Areal disturbance of cut slopes for the Horse Creek roads ranged from 0.0012 to 0.0034 square miles per mile of road length. The two sections of Standard I road had the greatest areal disturbance in cut slopes. Standard I roads were designed with current standards; smooth traffic flow and a minimum design speed of 15 miles per hour were design considerations; not the minimization of cut and fill slope heights. Cut slopes were 1:1 or 3/4:1, dependent on material for Standard I roads and 1/2:1 for cut heights less than six feet and 3/4:1 for larger cuts for Standard II roads.

Table 9.--The number of cut slope traps by height category for the Horse Creek roads.

Road	Station	Height Category 1	2	3	4	Total
9704	0+00-79+05	4	4	1	-	9
9704	79+05-129+37	4	5	-	-	9
9704	129+37-194+00	2	3	7	2	14
9704	194+00-238+70	4	2	1	-	7
9708	0+00-73+15	5	3	4	-	12
9709	0+00-64+48	5	3	2	2	12
	Total	24	20	15	4	63

Table 10.--Road and cut slope characteristics for the Horse Creek roads.

		Cut slope disturbance	Cut slope	Road	Trap installation	Cut slope height category 1	2	3	4	5[3/]
9704	0+00-79+05	0.0017	H	I	09-14-78	47.0	46.7	0.7	0.0	5.6
9704	79+05-129+37	0.0017	S/A	II	08-28-79	32.7	46.0	7.7	0.0	13.6
9704	129+37-185+10	0.0034	None	I	10-03-79	13.8	25.2	48.3	12.7	7.0
9704	185+10-238+70	0.0015	None	II	10-03-79	42.3	19.7	10.7	2.9	24.3
9708	0+00-73+15	0.0012	S/A	II	09-27-78	50.4	39.1	4.9	0.0	5.6
9709	0+00-64+48	0.0016	S/A	II	09-28-78	43.6	26.4	14.7	2.2	13.1

[1/] These values are based only on that length of road with cut slopes.

[2/] Category 5 is that portion of the road with no cut slopes, i.e., through fill sections.

[3/] H = seeded plus hydromulch, S/A = seeded plus a straw mulch with an asphalt tack.

The distribution of cut slopes by height categories may influence erosion quantities. Road 9704, stations 129+37 to 185+10 had the largest percentage of length of road with category 3 and 4 cut slopes, while all of the other roads had considerably smaller percentages in these cut slope height categories.

Cut slope stabilization treatment may also affect the amount and rate of erosion. Stabilization treatments included: no treatment, seeded and hydromulched, and seeded and a straw mulch with an asphalt tack.

The soils on these cut slopes contain 12.0% gravel, 69.4% sand, and 18.6% silts and clays. This texture is classified as a silty sand.

Analysis and Results

The volumetric measurements of eroded material from traps in the same height category were averaged and erosion volumes expressed as cubic feet of eroded material per 100 feet of cut slopes were calculated for the particular road or segment of road for selected time periods. One time period, referred to as summer, represents the erosion from the trap installation date or the first spring sampling date through the last sampling date in the fall. Erosion in this period is due to rain events and dry ravelling. The other time period, winter, represents the erosion from the last sampling date in the fall through the first sampling date in the spring. Erosion in this period occurs during snowmelt when cut material approaches saturation and is usually a small mass wasting type of erosion. Erosion by height category was weighted by the percentage of cut slope in that category for the particular road and summed to determine erosion for each road for the time periods (table 11).

Erosion data for the first summer following trap installation does not reflect actual erosion nor is it useful for between road comparisons. Several rainstorms occurred on the exposed cut slopes that produced an unmeasured quantity of erosion, prior to trap installation. Additionally, the completion date for the roads were different, therefore; erosion was influenced by more rainstorms on those roads that were completed earlier in the summer.

Erosion measurements since trap installation overestimate actual erosion. On many cut slopes, material eroded from the upper portion of the cut was deposited on the lower portion. This created a change in the slope of the cut slope but cannot be called erosion since it did not leave the slope. Cleaning the traps back to a baseline reference ignores the changing shape of the cut slope and overestimates erosion. In the summer of 1980 measurements were made of the change in shape of the cut slopes adjacent to each trap. This provided the information to correct total erosion through the summer of 1980. Overestimates were prorated for each sampling date.

Table 11.--Seasonal and cummulative cut slope erosion (weighted average) for the Horse Creek roads.

Road	Station	1978 Summer	1978-79 Winter	1979 Summer	1979-80 Winter	1980 Summer	Cummulative total
		----------ft^3/100 ft of road----------					
9704	0+00-79+05	0.52	23.38	11.11	46.74	15.49	97.24
9704	79+05-129+37	-	-	1.20	18.96	11.06	31.22
9704	129+37-185+10	-	-	11.20	102.41	52.20	165.81
9704	185+10-238+70	-	-	2.32	17.17	3.09	22.58
9708	0+00-73+15	0.00	7.29	2.83	18.33	8.09	36.54
9709	0+00-64+48	0.00	35.14	0.92	26.97	5.71	71.44

Total cut slope erosion for those roads constructed in 1978 ranged from 36.54 to 97.24 ft^3/100 ft of road. For those roads constructed in 1979, cut slope erosion ranged from 22.58 to 165.81 ft^3/100 ft of road. Total erosion increased as the areal disturbance in cut slopes increased (figure 8). Road 9704, station 129+37 to 185+10, had more than twice as much areal disturbance in cut slopes than other roads. Cumulative cut slope erosion from this road was large, 165.81 ft^3/100 ft. This road also had the largest percentage of category 3 and 4 cut slopes and did not receive any stabilization treatment.

Typically, the cut slope erosion was much larger during the winter sampling period. For example, for road 9704, stations 0+00 to 79+05, 72% of the total erosion was measured during the winter sampling periods. During spring snowmelt, as the cut material becomes saturated, material sloughs to the ditch. Also, freeze-thaw processes may cause erosion during spring snowmelt. Summer erosion as dry ravel or generated from rain events is much less than winter erosion.

Table 12 shows the total erosion by height categories for the various roads. Typically there is an increase in erosion with increasing cut slope height category. On the average, categories 2, 3, and 4 were greater than category 1 by factors of 5.5, 7.5, and 10.0, respectively.

There is no indication of a decrease in cut slope erosion with time, based on two years of data (figure 9). Cut slope revegetation has been sporadic; some areas have a good standing crop of grasses, while on other areas vegetation is absent. Of course, on those areas where sloughing occurred there is no vegetation. In the summer of 1981 ditch cleaning and maintenance are planned. This activity may accelerate cut slope erosion by undercutting the slopes.

Statistical evaluations of cut slope erosion between roads, between height categories, and between seasons are planned for completion this winter. Also, models expressing cummulative erosion as a function of time and/or precipitation and erosion rates as a function of time will be developed.

Stereo photogrammetric techniques are also being used to quantify cut slope erosion. There are now a total of 55 cut slope plots available for stereo photos. Presently, none of the stereo pairs have been mapped. These photos now reside at the geometronics service center in Salt Lake City. Due to equipment and programming difficulties they have not been able to map these photos. They expect to solve their problems this winter, at which time they will determine if they can quantify cut slope erosion from these photos and what the costs will be.

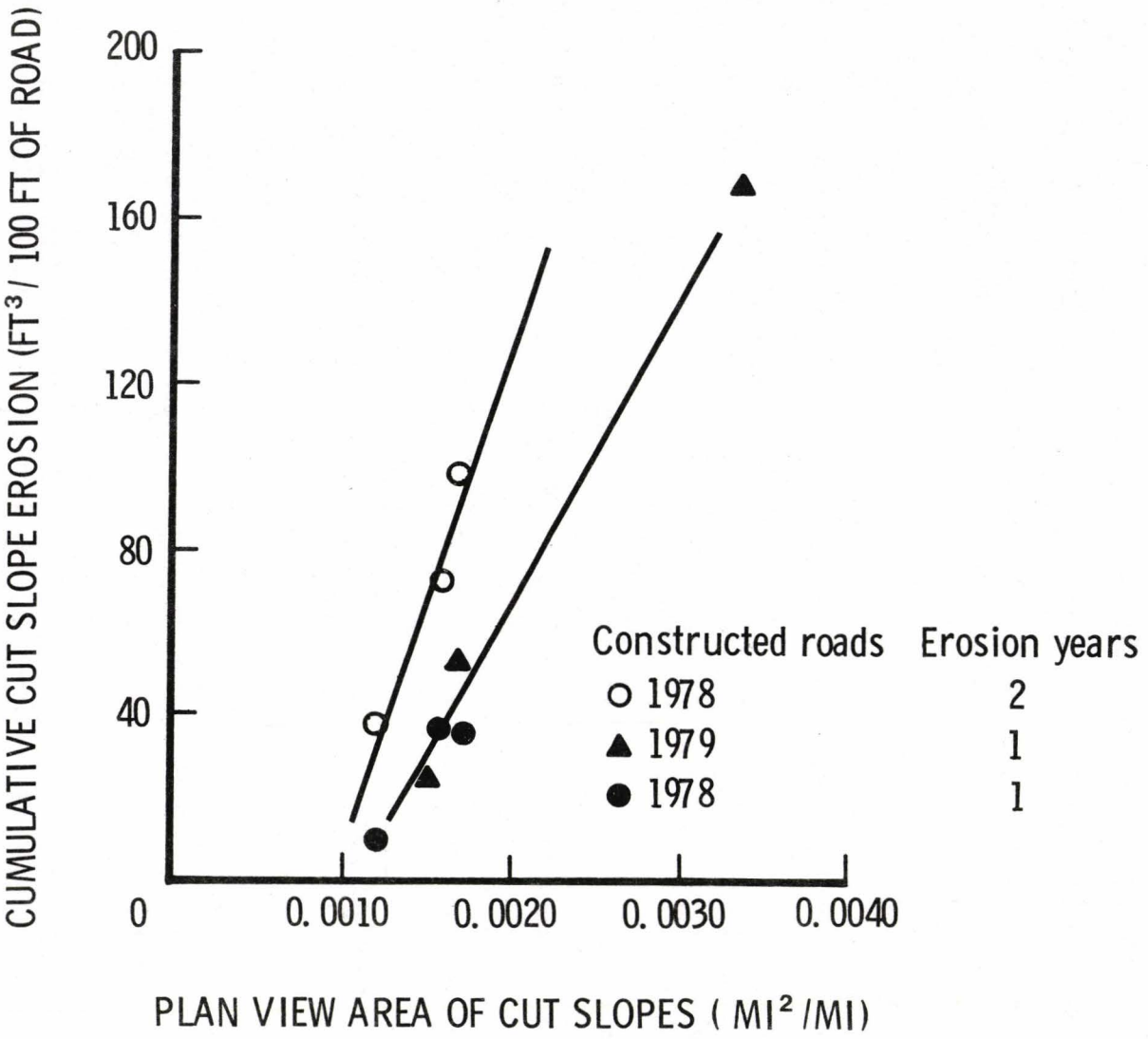

Figure 8.--The relationship between the areal disturbance of cut slopes and average cumulative cut slope erosion.

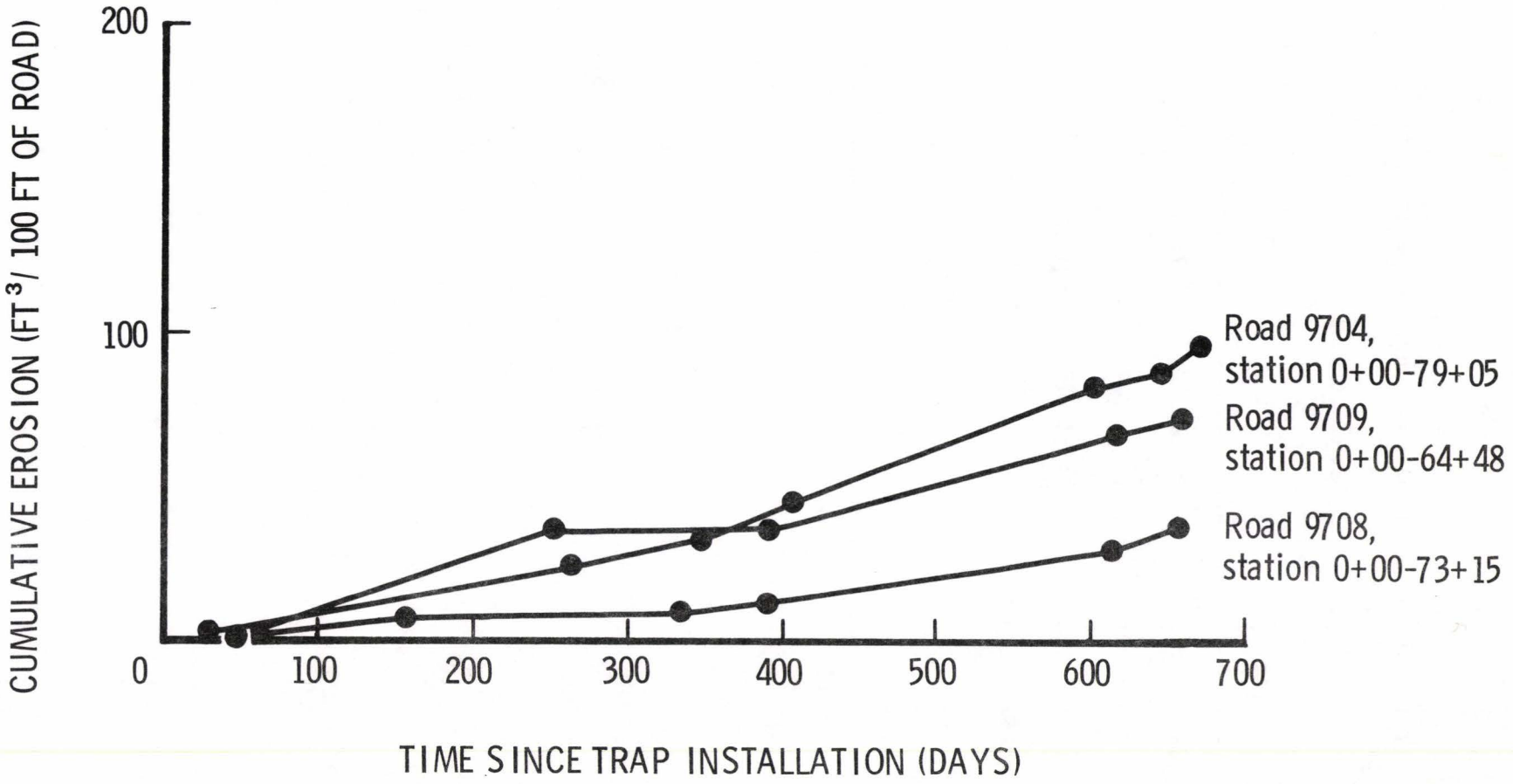

Figure 9.--Cumulative average cut slope erosion for those Horse Creek roads constructed in 1978.

Table 12.--Total cut slope erosion by height category as of mid-summer 1980 for the Horse Creek roads.

Road	Station	Height categories 1	2	3	4	Construction year
9704	0+00-79+05	20.19	173.93	145.45	-	1978
9704	79+05-129+37	4.07	55.76	-	-	1979
9704	129+37-185+10	22.75	79.66	222.46	262.14	1979
9704	185+10-238+70	13.40	10.89	86.25	-	1979
9708	0+00-73+15	17.80	48.31	135.14	-	1978
9709	0+00-64+48	27.75	78.96	162.87	232.51	1978

SUMMARY

Cut slope erosion occurs as dry raveling in the summer and as slumping during saturated conditions in late fall or during spring snowmelt. Slumping occurs on the fill slopes also, but surface erosion during summer rains also is significant. Rainfall and subsequent overland flow generated during the first few convective storms following construction accounts for the majority of fill slope erosion on some of the roads.

Seasonal differences in erosion on cut and fill slopes are well documented for road 9704, stations 0+00 to 79+05, for two years following construction. Average cut slope erosion was 70.1 and 27.1 ft^3/100 ft of road for the winter and summer sampling periods, respectively. Total fill slope erosion for the winter and summer periods was 4.2 and 17.6 ft^3/100 ft of road, respectively. Typically, fill slope erosion tends to be greatest during the summer and cut slope erosion is greatest during the spring snowmelt.

The change in seasonal erosion over the last two years was different for the cut and fill slopes. There has been no appreciable decline in cut slope erosion; however, fill slope erosion decreases rapidly with time to a constant small rate.

Table 13 illustrates the differences between cut and fill slope erosion by height class. Cut slope erosion was larger than fill slope erosion, and the difference becomes larger as slope height increases. This table also shows that erosion increases, for either cut or fill slopes, as the slope height increases.

Although sampling intensity was small and the erosion processes is highly variable in space, we feel that cut slope erosion is greater than fill slope erosion for two years following road construction and cut slopes will continue to produce more eroded material than fill slopes as time progresses.

Table 13.--Total mean slope erosion by height category, as of mid-July, 1980 from Horse Creek roads constructed in the summer of 1978.

	Height category 1	2	3	Weighted average
	---ft^3/100 ft of road--			
Cuts	21.91	100.40	147.82	68.54
Fills	20.47	45.40	52.82	34.55
% Difference	7.0	121.2	179.9	98.4

SECTION 8

THUNDERSTORM EFFECTS ON STREAM DISCHARGE AND SEDIMENT TRANSPORT IN RECENTLY ROADED WATERSHEDS

INTRODUCTION

There is a critical need for comprehensive data that characterizes thunderstorm effects on roads and their resultant impacts on the watershed. The best vehicle for extrapolation of Horse Creek data to other watersheds is the calibration and testing of models which can account for these effects. A major objective of the automatic A,B,C, stations is to enhance the quality and quantity of data from rainfall-runoff events for future modeling efforts.

Long term runoff events such as spring snowmelt require a much less sophisticated sampling scheme than thunderstorms since the melt can be anticipated and a time lapse sampling scheme can be initiated. A combination of rainfall interrupt and threshhold stage sensors are needed to provide proper instrument sensitivity and sampling sequences for automated monitoring of intermittent short duration thunderstorms. Improvements have been and are continuing to be made that will provide the most versatile sampling scheme possible for the automatic stations.

In the near future, a prototype microprocessor based data acquisition system will be tested at one of the automated crossings. It is hoped that this system will speed up the process of data analysis, fill the sampling voids currently left by commerically available equipment, and maximize the utility of the data that is collected. The data obtained with this system will be used to isolate specific storms and determine the net effect of that event in the delivery and disposition of sediment in the watershed.

An Example Thunderstorm

At this time, a sufficient number of thunderstorms have not been monitored and analyzed to develop actual relationships or time trends between storm size and sediment production for thunderstorm events. This discussion will therefore be limited to the data collected in watershed 16 during a storm which occurred on August 23, 1979. Figure 1 illustrates the instantaneous hydrographs in ft^3/sec at the A and B gages for this event. The total precipitation and storm duration were 0.7 in (1.78 cm) and 1 hour, respectively. According to the NOAA Precipitation Frequency Atlas (1973), this depth-duration approximates a five year return period storm for the Horse Creek area.

One visual effect of the road on these hydrographs is the rapid response at the 16B station. This can be explained for a combination of reasons which include: (A) loss of interception storage due to right-of-way clearing, (B) loss of surface detention storage due to grubbing of the right-of-way, (C) decreased infiltration due to the compaction of the roadbed, and (D) decreased time of concentration for surface runoff due to the road drainage system.

An estimate of baseflow was made for the hydrographs from the A,B,C, and mouth gages to determine the net storm runoff at each location. Table 1 presents these data. The net storm runoffs in ft^3 were used to determine the areal runoff depth in inches for the area tributary to that gage. The average runoff depth for the entire watershed was 0.03 inches (0.08 cm). At the 16A station this depth was 0.02 inches (0.05 cm). The net storm runoff at the 16B station was subtracted from the A station and the excess volume was assummed to have originated entirely from the road which gave an areal runoff depth of 0.1 inch (0.25 cm). The assumptions which are needed for these calculations suggest an average infiltration of 0.6 inch (1.52 cm) for those portions of the road prism which are adjacent to the 16B station. In reality little or no infiltration may have occurred on the road surface while the cut slope may have produced little runoff.

Thorough field measurements need to be taken of infiltration rates on the various portions of the road prism and in the watershed. In the undisturbed watershed, surface runoff probably occcurred from a small portion of the total basin, i.e., the saturated riparian zone immediately adjacent to the stream. If this is the case then the areal runoff depth for the watershed may equal that of the road. However, there is a measurable (42%) increase in runoff volumes between the A and B stations and most of this increase must be attributed to the road prism. This additional runoff is an obvious concern because of the potentially deleterious effects it could produce on the aquatic system. Many more thunderstorms must be monitored and other supporting field data on infiltration rates and other site specific physical characteristics are needed before accurate projections can be made with the thunderstorm data and their impacts can be assessed.

Figure 2 illustrates the instantaneous sedimentgraphs (lb/sec) at the A,B, and C stations for the August 23 storm period. Table 2 presents the sediment transport characteristics at the A,B,C, and Mouth. At the sedimentgraph peaks there is a 5 fold increase in sediment concentration (lb/ft^3) between the A and B stations. Although the total storm flux (lbs) passing the B and mouth stations are very similar, the peak concentration at the B station is alsmost 26 times that at the mouth.

Skille (1980), reports that the Horse Creek channel transects indicate a net storage of sediment in the upper reaches of the streams during the summer and a flushing of these stored sediments downstream during the spring melts. These thunderstorm data would lend support to the hypothesis that rainstorms introduce increased amounts of sediment from the road prism to the stream but the low summer flows lack sufficient transport capacity to move all of this sediment downstream which results in a net storage of material. This is supported in part by a decrease in sediment flux between the B and C stations for the storm period.

Table 1.--Storm hydrograph characteristics for drainage 16, noon of August 23 to noon of August 24, 1979.

Station	Tributary area	Total runoff	Baseflow	Direct runoff	Peak discharge	Time of peak
	acres	ft^3	ft^3	ft^3	ft^3/sec	hr
16A	6.46	1440.0	1050.1	389.9	.063	2055
16B	6.78[1/]	2051.3	1546.9	504.4	.089	2054
16C	21.2	2372.4	1626.5	745.9	.09	2110
Mouth	68.25	12736.0	5294.3	7441.7	.776	2100[2/]

[1/] Includes 0.32 acres of road prism.

[2/] Based on mean hourly discharge.

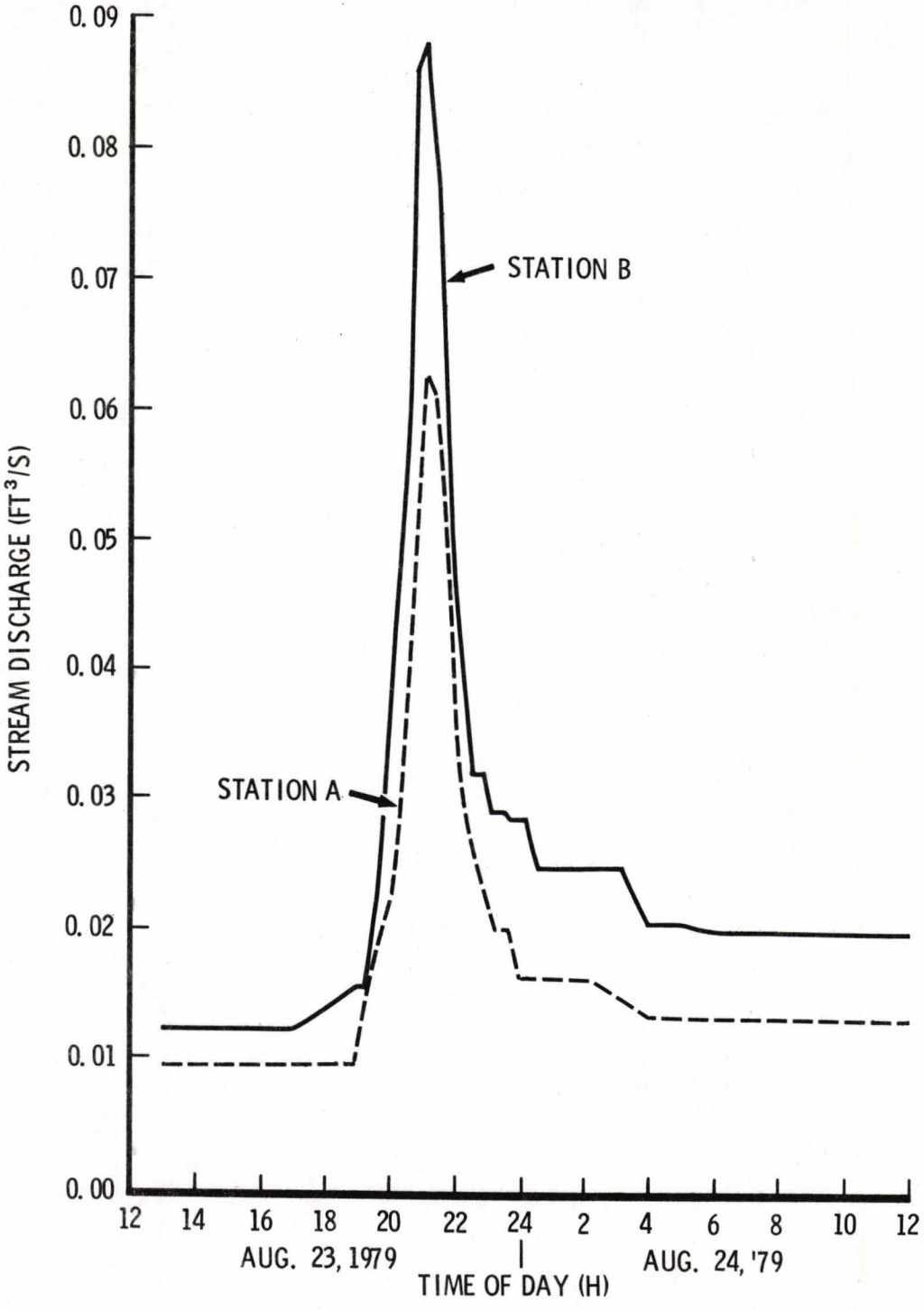

Figure 1. Stream discharge at the A and B sampling stations in watershed 16 (crossing 16-2) during and following the thunderstorm of August 23, 1979.

Table 2.--Storm sedimentgraph characteristics for drainage 16 on August 23-24, 1979.

Station	Tributary area	Total flux	Peak concentration	Peak flux	Time of peak flux
	acres	lbs	lb sed/ft^3 H_2O	lb sed/sed	mil time
16A	6.46	1.51	.0079	.00033	2040
16B	6.78 (.32 road)	9.54	.041	.0026	2036
16C	21.2	5.42	.021	.0015	2036
Mouth	68.25	8.32	.0016	.0012	2100[1/]

[1/] Based on mean hourly discharge rate (ft^3/sec)

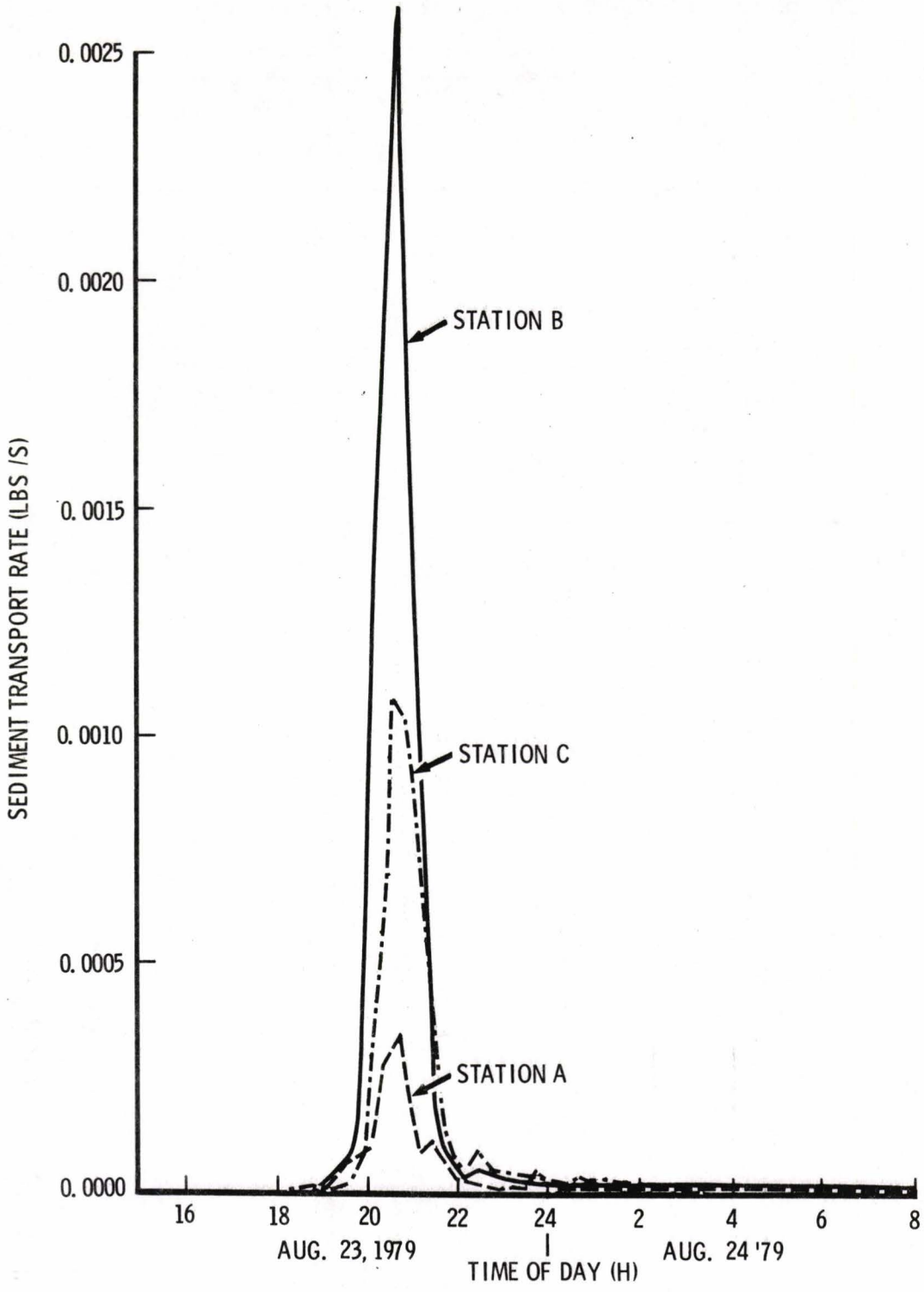

Figure 2. Sediment transport rate at the A,B and C stations in watershed 16 (crossing 16-2) during and following the thunderstorm of August 23, 1979.

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SECTION 9

EFFECTS OF FOREST ROADS ON STREAM SEDIMENT

EFFECTS OF FOREST ROADS ON STREAM SEDIMENT

John King[1/] and Michael Gonsior[2/]

ABSTRACT

This paper discusses some on-site erosion and stream sedimentation consequences of forest road construction in small watersheds in northern Idaho. Pioneering and culvert installation increase sediment fluxes in the streams, just below the road, 100 to 10,000 times the normal daily flux for short periods of time. Subsequent to construction, rain and snowmelt events acting on the road prism features appreciably increase sediment fluxes in the streams just below the roads. Sediment measurements at the mouths of these small watersheds indicate that very little of the road derived sediment is being transported out of the watersheds. Thus, sediment is being stored in the channel systems. Channel transect data supports the conclusion that the channels are aggrading as a result of storage of road derived sediment.

Erosion and sediment transport are very dependent on climatic events and the resulting streamflow. Thus, the results could have been substantially different under a different set of climatic events. Current and future research is attempting to calibrate existing physical process models which would enable prediction of the erosion rate and sediment fluxes for different climatic events.

INTRODUCTION

The Horse Creek Administrative-Research Study area was established in 1965 as a field laboratory for determining the effects of alternative forest management practices on streamflow and water quality. The Horse Creek watersheds are located in the north central portion of Idaho within the Nezperce National Forest, approximately 35 air miles east of Grangeville, Idaho (Figure 1). Horse Creek flows easterly into Meadow Creek, 4 miles above its confluence with the Selway River.

The watershed lies on the border of the Idaho Batholith, a large igneous intrusion in central Idaho and western Montana. The parent material is part of the Belt Super Group (Bennett 1974) composed of sedimentary and metasedimentary rock of primarily gneissic material (Greenwood and Morrison 1967). The deeply weathered soil is a well drained sandy loam to loam. Median side slopes are 31 percent, but slopes in excess of 65 percent are common. In an undisturbed condition there is little evidence of any surface erosion and stream sediment is predominately derived from channel sources. However, there is a high potential for surface erosion following disturbance of the forest floor. Thunderstorm activity during the summers and rapid spring snowmelt provide conditions conducive to accelerated erosion especially on disturbed sites.

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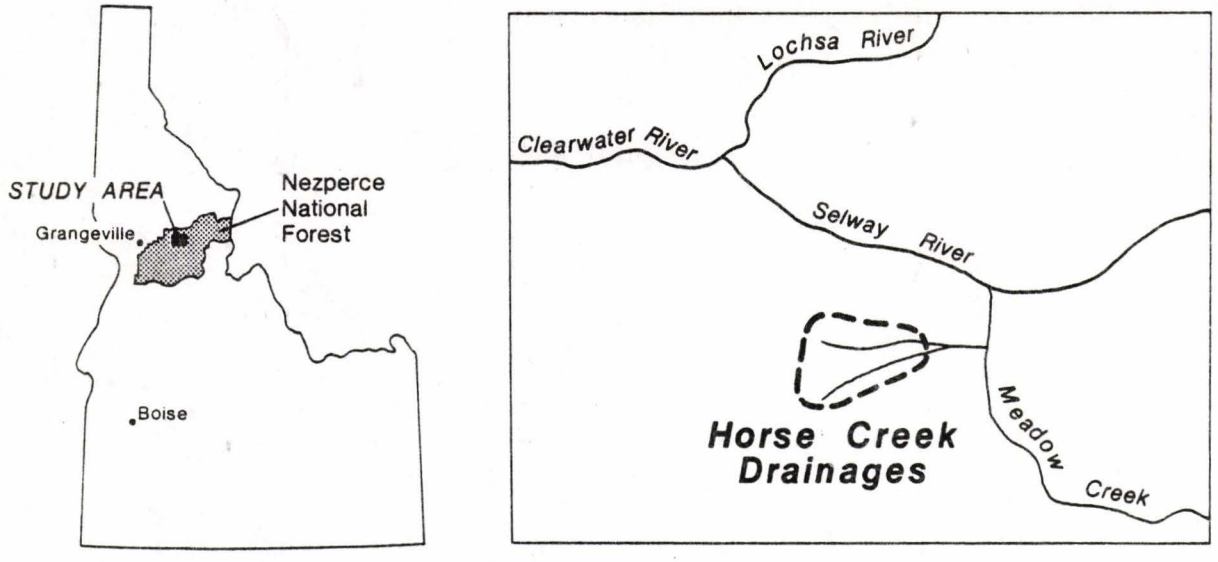

Figure 1. Location map for the Horse Creek Administrative Research Study Area.

One of the studies in this area focuses on determining rates of erosion from various parts of forest road prisms, and subsequent downslope and in-stream disposition of the resulting sediments. The monitoring scheme is designed to provide data on erosion and sediment transport rates at various locations in the watersheds, from the sites of disturbance to the watershed outlets. Ultimately, these monitoring systems will be used to test predictions of various water and sediment routing models. However, currently we can only describe some of our observations and draw some inferences on the occurrence and magnitude of various processes.

THE SITUATION

Forest roads are necessary or desirable for many reasons; notably for the removal of forest products. In the past, much of the logging and road building occurred on relatively gentle terrain and at a time when public concern about impacts on water quality was relatively mild. Now, steeper and more rugged terrain is being entered and public concern about water quality and other environmental impacts is relatively strong.

Many studies in the western United States have shown that forest roads are the major source of sediment and a major cause of water quality degradation. Megahan (1972) stated that "roads create a disproportionate share of the problem, probably greater than 90 percent in most instances." Timber harvesting, reforestation, site preparation and other silvicultural practices generally contribute less sediment to streams.

The impacts of forest roads on streamflow and sediment concentrations are most apparent during road construction and during subsequent rainstorms and snowmelt events. The amount of sediment introduced into a stream channel during construction depends on the methods and care employed during pioneering and culvert installation operations,

the nature of the climatic events and the magnitude of streamflow. During subsequent rainstorms and snowmelt events, the amount of sediment contributed to a stream channel largely depends on the physical characteristics of the road and the rate of restabilization of the disturbed areas.

Once sediment enters a stream, its subsequent disposition depends on the organic debris loading in the channel, the hydraulic properties of the stream channel and the magnitude of streamflow. The significance of naturally derived and extraneous sediment depends on downstream water uses and in-stream values such as fisheries habitat.

PURPOSE

Our purpose is to describe some of our observations relative to the amounts and disposition of sediment contributed by forest roads, during construction and throughout the following two years and to assess the relative contribution of various road features to stream sedimentation. We will also describe some preliminary indications related to the effects of road-derived sediments on channel bottom composition, channel storage and aquatic habitat.

METHODS

Figure 2 is a map of Horse Creek delineating the six roaded subdrainages, road locations, stream crossings, and other pertinent features. These subdrainages range in size from 70 to 364 acres. A sediment dam, H-flume and stage recorder are located at the mouth of each subdrainage. The flumes and stage recorders provide continuous streamflow records.

Also located at the mouths of the roaded watersheds and control watershed 6 (figure 4) are automatic water samplers. These devices take discrete time based samples and have been set up to sample twice a day during most of the study period. Analysis of the suspended sediment concentrations of these samples allows for determination of sediment quantities passing through the sediment dams.

The sediment deposited in the dams at the watershed mouths is measured annually using a sag-tape surveying technique. Thus, the total sediment leaving a subdrainage during any year can be estimated by combining the amounts in the dams with the amounts passing through the dams as suspended sediment.

Along the logging roads, monitoring stations have been installed at all live water crossings (Figure 2). At each stream crossing there are three monitoring locations (Figure 3). The A stations are located just upstream from the culvert inlets. Natural sediment transport is measured at these stations. The B stations, at the culvert outlets, measure the combination of natural sediment plus sediment derived from some identifiable lengths of cut slope and ditch and road surface area. The C stations are located approximately 100 yards downstream from the B stations. The measurements at the C station enable detection of sediment that may enter the stream between the B and C stations as a result of overland transport from definable segments of the fill slopes. In the absence of overland transport, the data from the B and C stations provide evidence of channel aggradation or degradation between these stations.

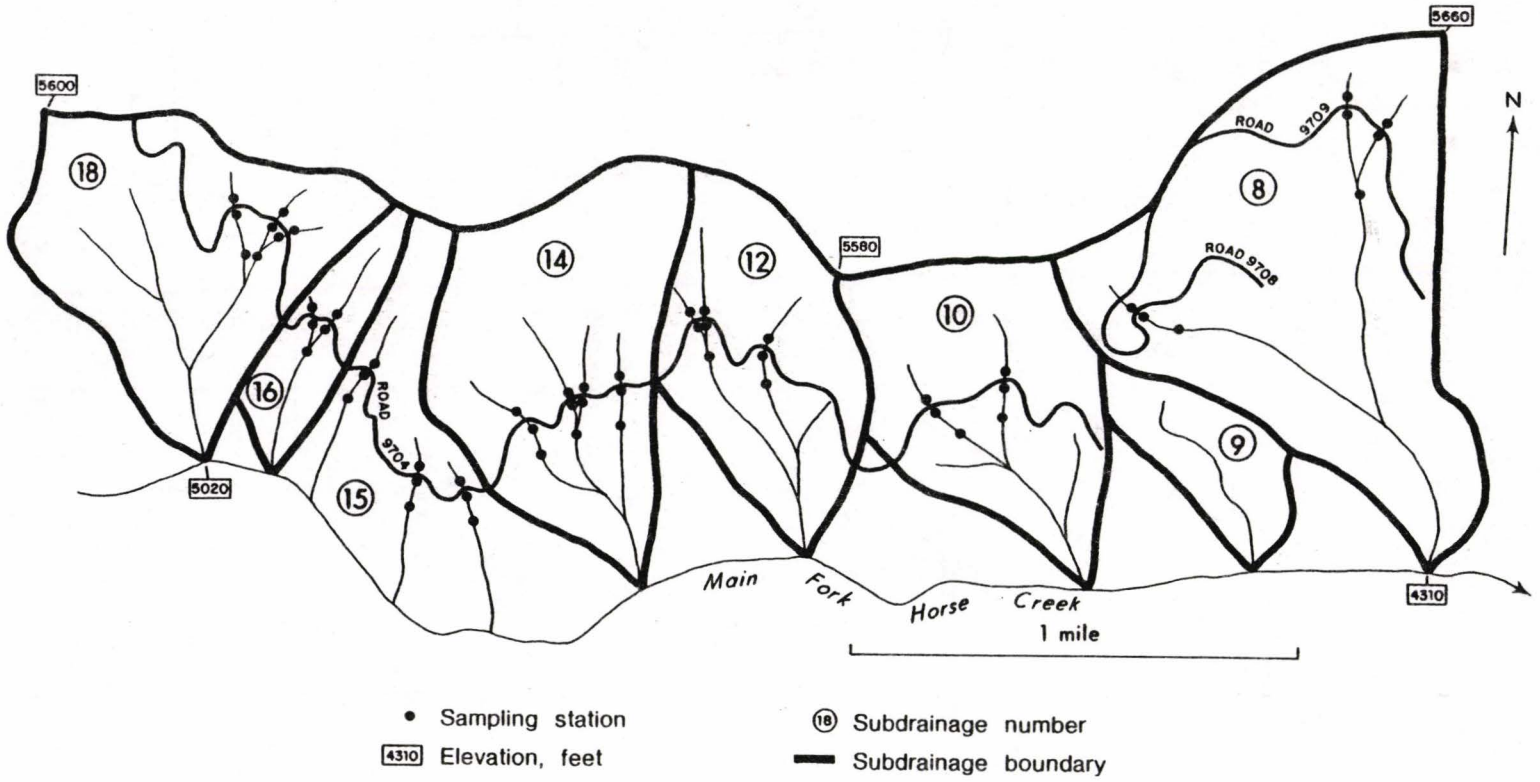

Figure 2. A map of the roaded Horse Creek subdrainages showing the location of the roads and sampling stations.

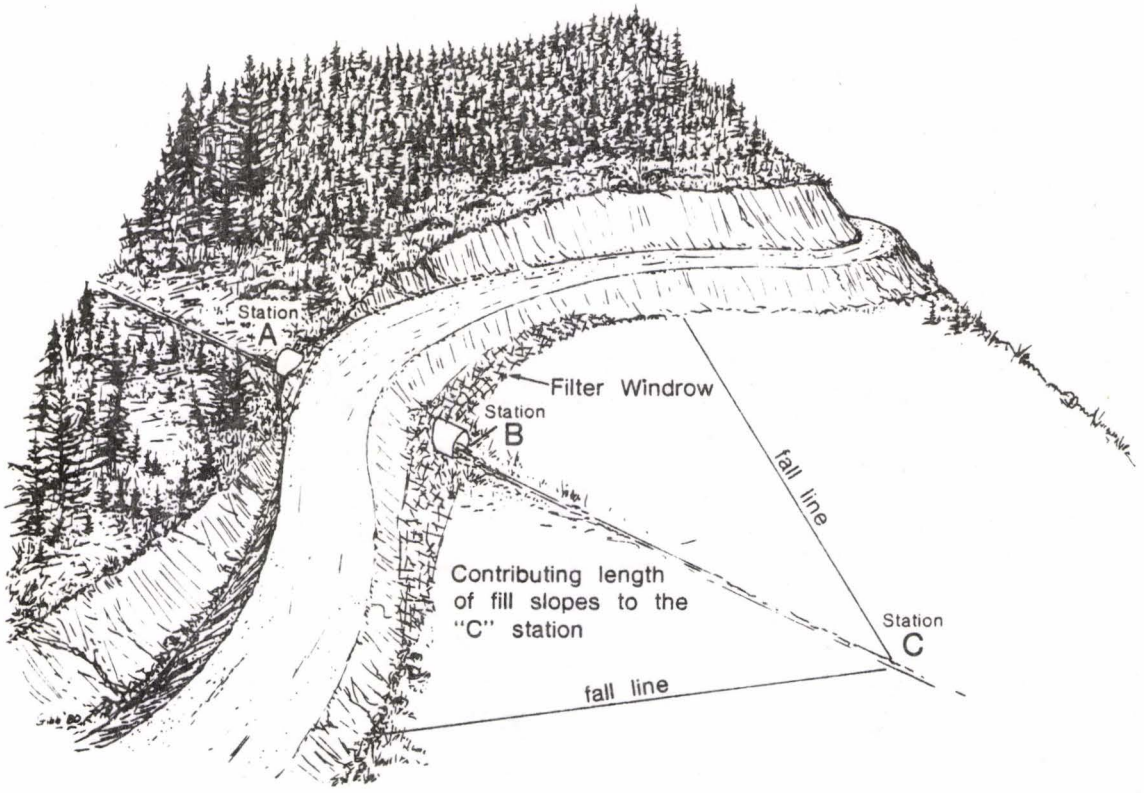

Figure 3. The sampling station locations at each live water crossing.

At each of the A, B, and C stations a small wooden flume was installed to concentrate flow and elevate the streams. Water samples are collected at the outlets of these flumes and analyzed for total sediment concentrations. Discharge measurements are determined using a bucket and stopwatch method. Sediment samples and discharge measurements at these stations are taken twice a week throughout periods of snowmelt and monthly during late summer and fall low flow periods. Selected stream crossing stations are intensively sampled during rainstorm events.

Continuous monitoring stations were installed at the A, B, and C stations at four selected stream crossings (Figure 4). Stage recorders and H-flumes provide continuous streamflow records. Automatic water samplers take samples for analysis of total sediment concentrations based on intervals of discharge or time. The data from the continuous monitoring stations should enable simulation of complete records at other crossings where only periodic manual samples are taken.

In those streams which have continuous monitoring stations associated with the roads and in one control stream, measurements are made of channel aggradation and/or degradation and the particle size distribution of channel bottom material (Figure 4). Six representative channel reaches, approximately 30 feet in length, are surveyed twice a year, once following snowmelt and again in the fall. One sample channel reach is located above the road, two are located between the B and C stations and three are located between the C station and the mouth. The spatial distribution of these channel reaches allows us to trace the road effects downstream.

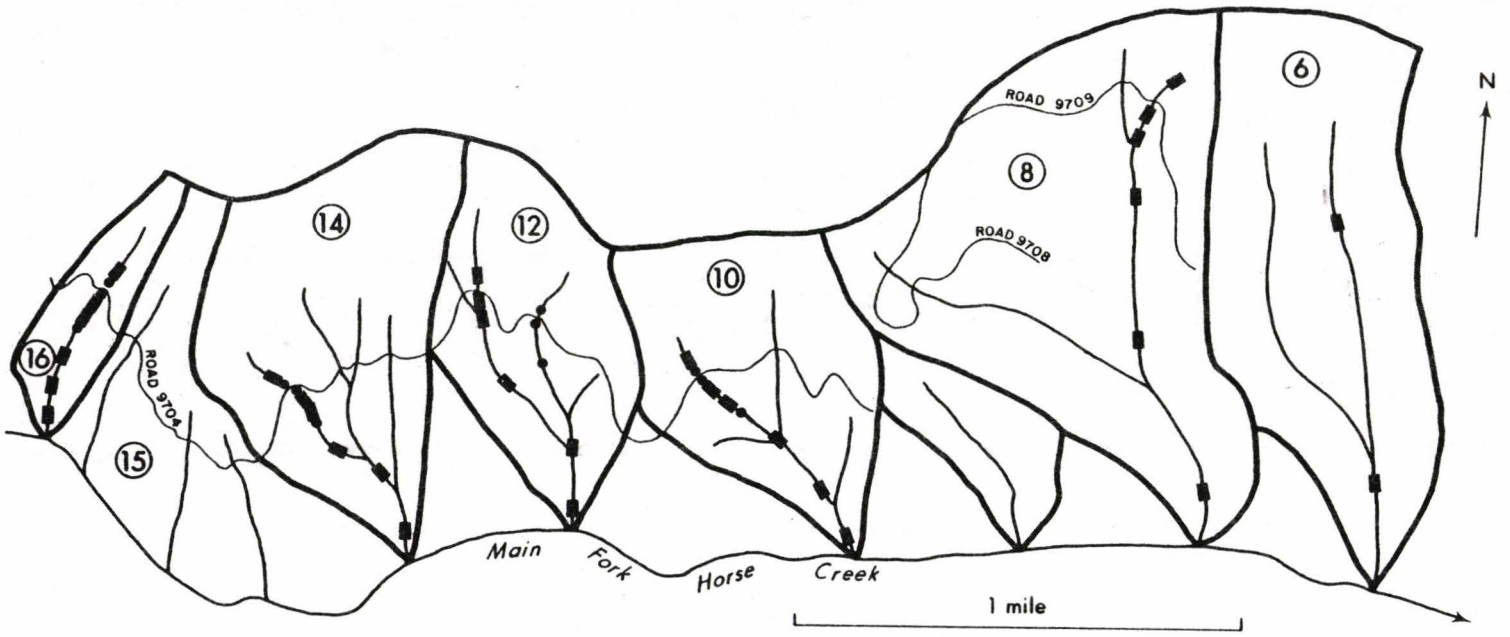

Figure 4. The location of the automatic sampling stations (•) and the channel transects (▬) in the roaded Horse Creek subdrainages.

Finally, to enable estimation of erosion on cut and fill slopes, a variety of techniques have been used. Four-foot long traps are used to collect eroded material at the base of cut and fill slopes. Volumes of eroded material in the traps are measured following snowmelt, after major thunderstorms and in the late fall. Also, a complete survey of rills and gullies in the fill slopes is conducted after snowmelt and in the late fall. Measurements are made to determine the volume of material leaving the fill slope and the downslope transport distance of the material on the forest floor. In addition, we are experimenting with the use of close range stereophotography to estimate cut slope erosion. Stereo pairs are taken twice annually to determine erosion during snowmelt and erosion during the summer and fall rain season.

RESULTS

Road construction was completed in subdrainages 18, 16, and 8 during the summer and autumn of 1978, and in subdrainages 14, 12 and 10 during the 1979 construction season. Presently, we have data for the first year following construction for subdrainages 18, 16 and 8. We will present and discuss a limited range of measurements and observations; primarily focusing on subdrainage 16.

We preface this discussion by pointing out numerous difficulties and deficiencies in our methods during the first year of this study. At the continuous monitoring stations we utilized commercially available water samplers that provided us the choice of either sampling at fixed intervals of time or of flow proportional sampling. Unfortunately neither technique is adequate for monitoring construction events or short duration rainstorms. Thus, we relied heavily on manual sampling during construction and storm events following construction. Storm events which occurred at night or on weekends were not sampled. Moreover, the effort required to conduct an extensive monitoring program with limited personnel often meant that only a single sediment sample and discharge measurement was acquired at each of several locations during a rainstorm event.

Due to these deficiencies, we are presently only able to relate order of magnitude changes in sediment concentrations during road construction activities and the subsequent year. The amounts and disposition of road contributed sediment are at best rough estimates. As will be discussed later, we have been and will continue to make improvements in our methods, which will result in considerably greater resolution and comprehensiveness in our future efforts.

Preconstruction Watershed Behavior

Stream discharge at the mouths of these watersheds are in the range of 10^{-2} to 10^{-1} cfs during summer low flow periods, and as low as 10^{-3} cfs at some road crossings. Low flow sediment concentrations range from 1 to 10 mg/1.

During high intensity rainstorm events, stream discharge and sediment concentrations increase by one to two orders of magnitude. Thus, a stream ordinarily flowing at 0.05 cfs during the summer with sediment concentrations of 1 mg/1 might, during a storm event, increase

to 0.5 cfs with a sediment concentration of 100 mg/1. Correspondingly, the sediment flux would increase from the low flow level of 0.01 lbs/hr to approximately 10 lb/hr.

During spring snowmelt, streamflows increase to levels about two orders of magnitude greater than during low flows. Likewise, sediment concentrations increase by one to two orders of magnitude during the period of rising discharge, but during falling discharge the concentrations are usually less than one order of magnitude greater than those during low flow. Typically, the amount of sediment passing through the sediment dams at the mouths of the watersheds during the entire snowmelt hydrograph period of 40 to 50 days are in the range of 10^3 to 10^5 lbs; with peak fluxes in the range of 10^2 to 10^4 lb/day.

During Construction

The road construction season began shortly after spring runoff, when discharges were still as much as 10 times higher than their lowest summer discharges, and extended until late autumn. There were two periods of major disturbance at any given stream crossing: (1) during the pioneering phase, when right-of-way timber and debris was cleared from the stream channel and a temporary culvert was installed, and (2) during replacement of the temporary culvert with a permanent culvert. Figure 5 illustrates the sediment concentrations at various locations during these activities in a stream in subdrainage 16. The estimated total contributions to the stream during pioneering and permanent culvert installations were 12.3 and 0.2 lbs., respectively, or the equivalent of about 45 days of summer low flow sediment delivery past the C station. Virtually none of the sediment passing the C station during these activities reached the watershed mouth indicating that this added material was stored in the channel. Similarly, the amount of sediment passing the C station during these construction activities was less than the total amount added to the stream. This implies that the difference was stored in the stream channel between the B and C stations.

Installation of the permanent culvert at the crossing in subdrainage 16 was preceded by diverting of the stream around the construction site. Thus, construction was "in the dry" (termed a dewatered culvert installation) and the impact to the stream was confined to the brief period during which the stream was returned to its natural channel. This caused a washing of the loosened material that resulted from construction disturbance above the culvert inlet and just below the culvert outlet. At other crossings, culvert installations took place "in the wet", with the stream running continuously through the construction site. Figure 6 shows the effects of one such installation compared with a dewatered installation. In this example of an "in the wet" culvert installation the total amount of sediment passing the C station was about 46 lbs, or the equivalent of about 113 days of summer low flow sediment delivery. This is substantially greater than the 0.2 lbs contributed to the stream during an "in the dry" culvert installation. Again, the fraction of sediment reaching the watershed mouth was negligible which implies storage of the sediment in the channel.

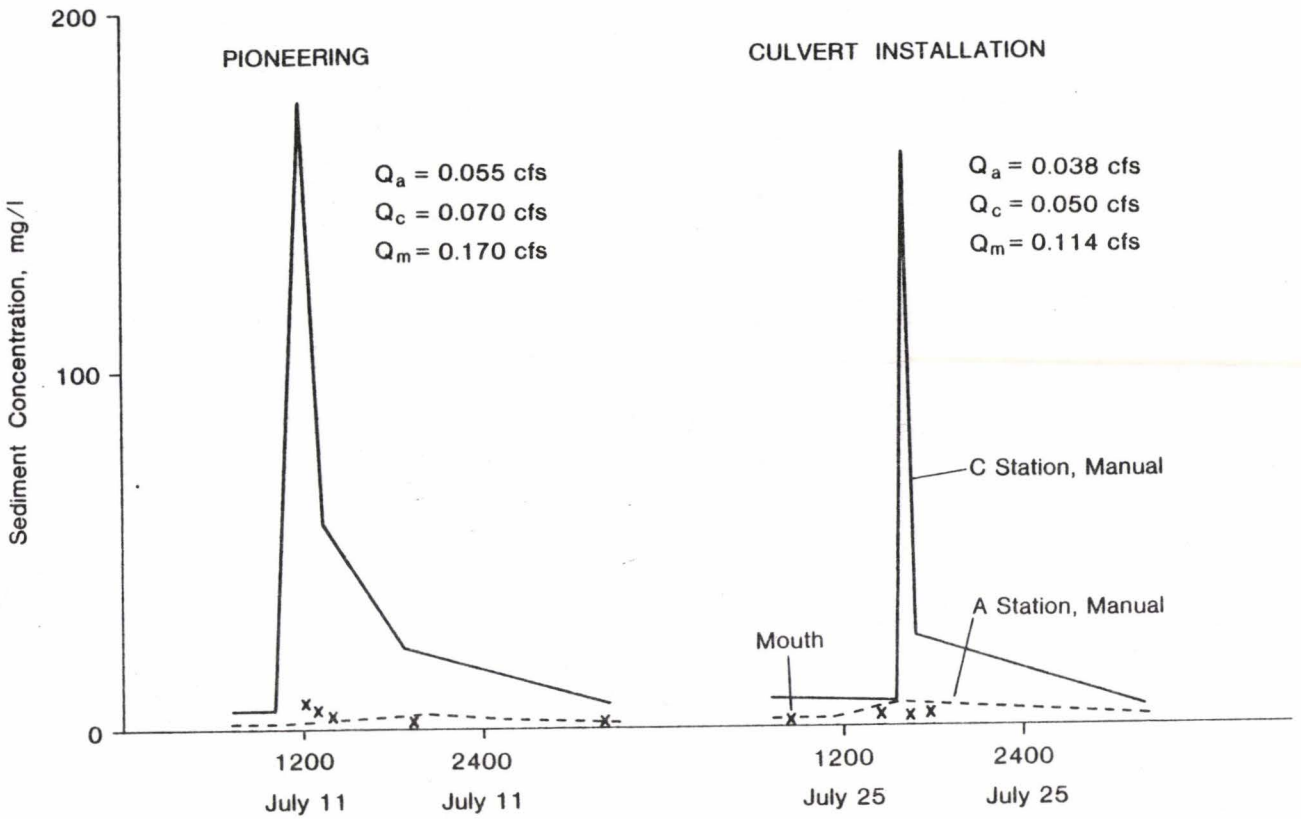

Figure 5. Sediment concentrations resulting from pioneering and culvert installation activities in subdrainage 16.

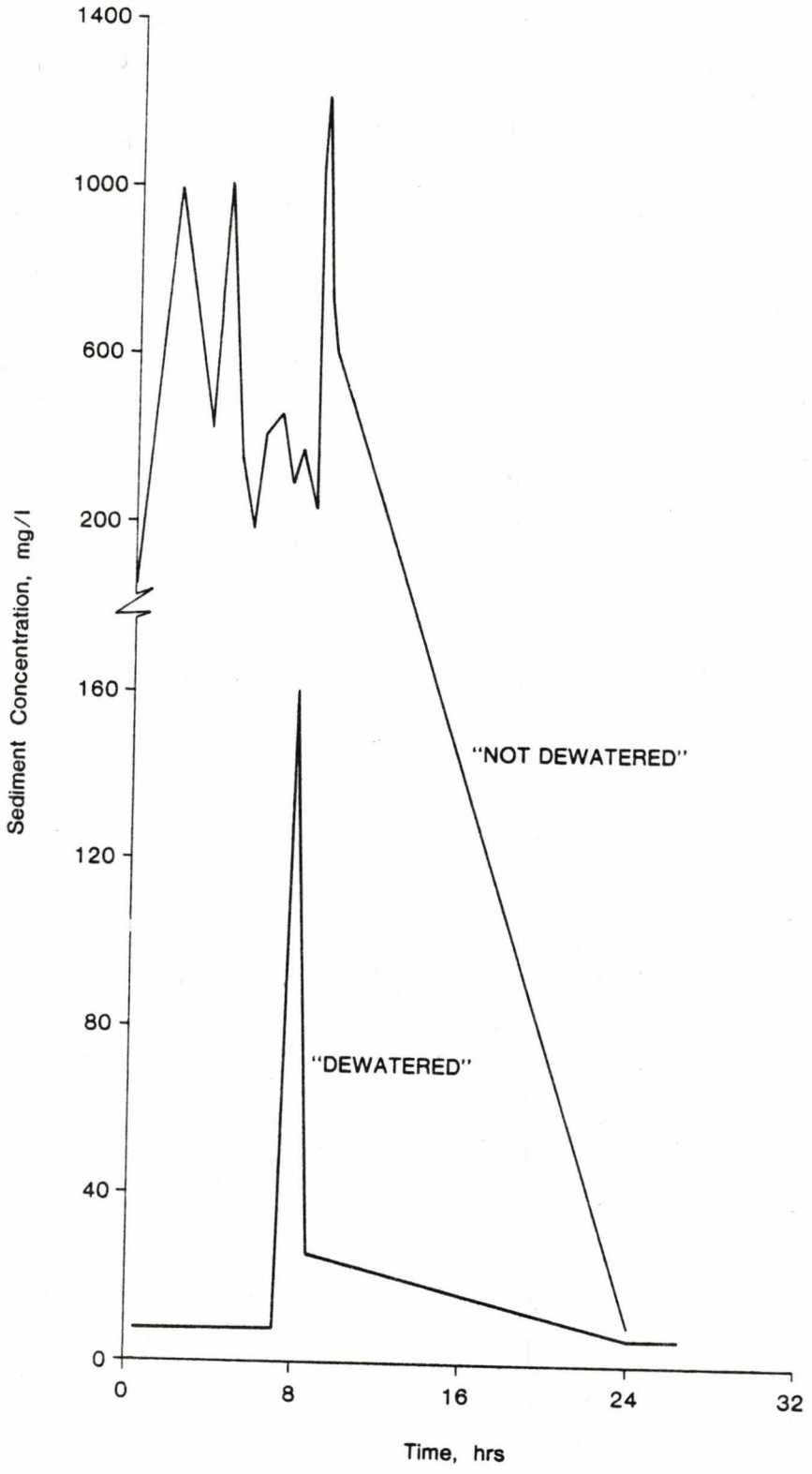

Figure 6. The sediment concentrations due to culvert installation at a "dewatered" site and a "not dewatered" site.

In summary, the amounts of material added to these small streams during construction activities is comparable to 100 to 10,000 times the normal daily sediment flux at these locations. Virtually none of this material was transported out of the subdrainage.

After Construction

During low flow periods, the sediment concentrations and streamflows measured below the newly constructed roads rapidly return to their preconstruction levels. However, during rainstorm events, especially those of sufficient intensity and duration to generate flows in the ditch systems, sediment concentrations at the B and C stations increase as much as 10^2 times those at the A stations. In many instances, the ditch flows were comparable to the flow rates at the A stations, resulting in an approximate doubling of flow rates at the B stations. Thus, the sediment flux at the A stations might increase from the low flow level of 0.005 lb/hr (2 mg/l at 0.01 cfs) to 0.2 lb/hr (40 mg/l at 0.02 cfs) and the flux at the B station might increase from 0.005 lb/hr to 35 lb/hr (4000 mg/l at 0.04 cfs). The ditch, during such an event, could contribute a flow equivalent to the A station, but with a sediment concentration of nearly 8000 mg/l.

In summary, during the first few rainstorms after construction, we estimate that sediment loadings due to the movement of newly exposed materials on the cut slopes, road beds and in the ditches, were in the order of 10^2 to 10^4 times the normal sediment fluxes at the B stations. The total additions of sediment from all of these storms were probably in the range of 10^2 to 10^3 lbs at each stream crossing. Once again, sediment concentrations at the mouths of the watersheds indicate that only a very small fraction of these quantities was transported out of the watershed during storm events, and that most of the material was stored in the channels.

As will be discussed later, significant fill slope erosion occurred during these initial storm events, but little or none of the eroded fill material was transported to the streams.

First Snowmelt Period After Construction

Figure 7 illustrates the streamflow hydrograph and sediment concentration relationships at the A, B, and C stations in subdrainage 16 for the 1979 snowmelt period. Approximately 500 lbs of sediment were transported past the A station and 900 lbs past the B and C stations. The ditch system, which contributes to the culvert inlet, approximately doubled the amount of sediment in the stream when compared to undisturbed or preroad levels.

During this same snowmelt season approximately 1400 lbs of sediment passed through the sediment dam and out of subwatershed 16. Based on pretreatment records, the expected yield would have been about 1200 lbs, virtually the same as after treatment.

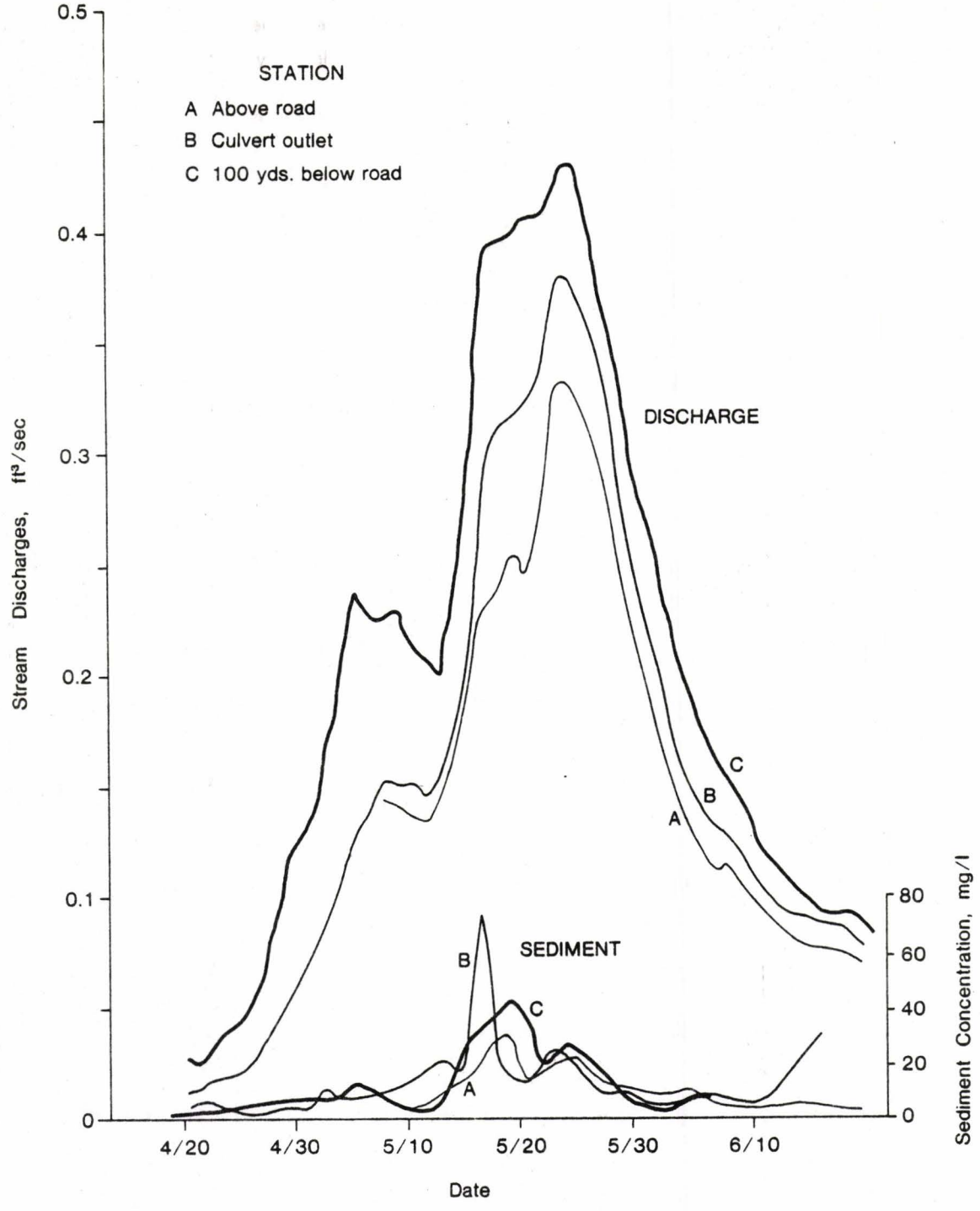

Figure 7. Stream discharge and sediment concentrations measured at the road sampling stations in subdrainage 16 during the snowmelt period of 1979.

Total Annual Sediment Production for the Watersheds

Figure 8 shows the relationship between annual sediment deposited in the sediment dams at the mouths of the subwatersheds and annual water yield. There is no apparent effect of road construction on the sediment yields for subdrainages 18, 16, or 8 during the first year following construction. This also implies that the road derived sediments are being stored in the stream channels.

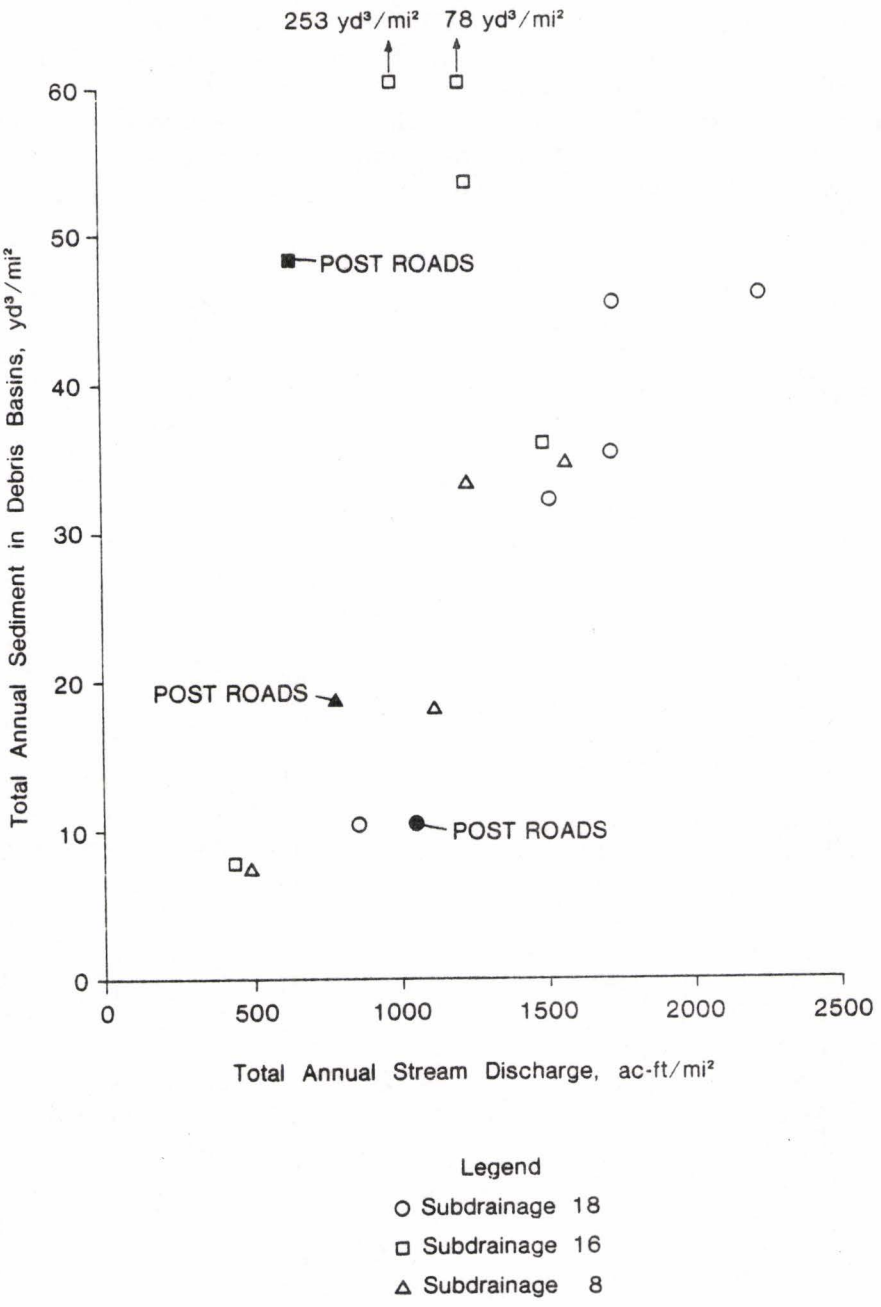

Figure 8. The relationship between total annual stream discharge and total annual sediment in the debris basins for the three subdrainages roaded in 1978.

Stream Transects

Figure 9 illustrates the aggradation and degradation of the stream channel transects subsequent to road construction. During the summer of road construction all of the transects show aggradation of the stream channel. During the first snowmelt period those transects located a short distance below the roads (transects 2, 3, and 4) degraded while those transects in the lower portion of the subdrainage (transects 5 and 6) aggraded. The average net elevational change of the stream channel transects in subdrainages 8 and 16 for the 18 months following road construction was + 0.27 inches. Although the absolute accuracy of the transect measurements is unknown, the data does indicate that road derived sediment is stored in the channel system, with the largest accumulations in the lower reaches of the channel.

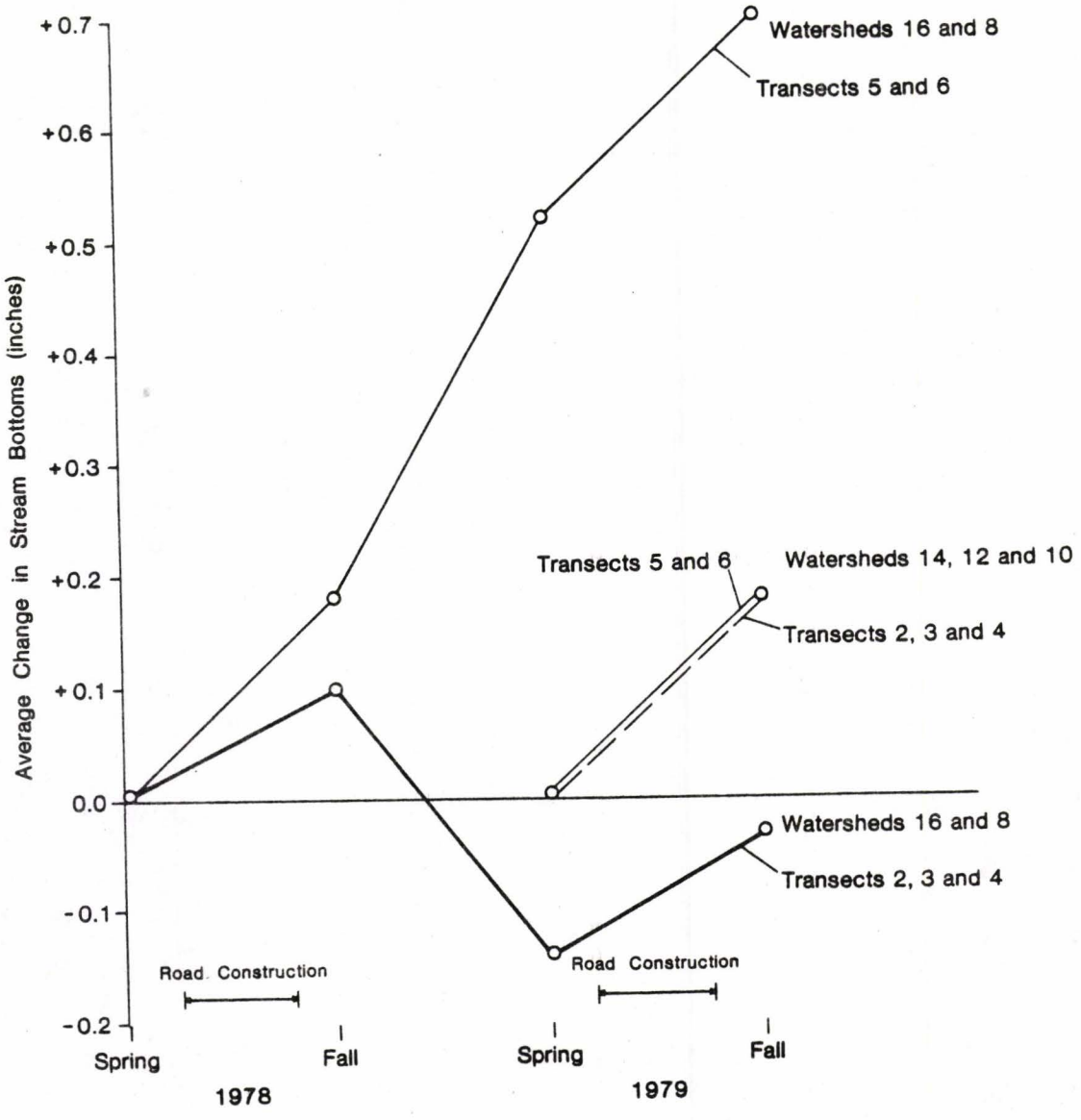

Figure 9. Channel transect aggradation/degradation following road construction in the Horse Creek subdrainages.

Summary of First-Year In-Stream Monitoring Results

We estimate that the amount of sediment contributed to the stream system in subdrainage 16 during road construction and the first year following construction, was a sizeable fraction of the average annual sediment production from this watershed. Most of this sediment remains in the channel system of the subdrainage between the road crossing and the subdrainage mouth.

Second Year After Construction

Figure 10 illustrates the effects of a major thunderstorm on August 23, 1979 that generated 0.7 inches of rainfall in approximately one hour. Sediment fluxes past the B and C stations were one order of magnitude greater than the flux past the A station. The total contribution of sediment at the B station was relatively small, only 8 lbs. This is considerably less than what was measured during thunderstorms the previous summer. It is hypothesized that there is now a lack of fine particulates on the road surface and in the ditches that can be transported to the stream. Sloughed cut slope material that enters the ditch system does not contain large quantities of fine particulates. Very little of this sloughed material is being transported to the stream. The contribution of sediment from this road crossing is diminishing as time progresses, and barring any extreme events, this trend should continue.

On-site Erosion

Erosion occurring on the cut and fill slopes was monitored with four-foot long unbordered traps at the base of the slopes. Sample intensity was less than one percent of the entire length of road; thus, this information does not accurately reflect total erosion volumes but does provide information on the relative magnitude of the cut and fill slope erosion and time trends in erosion rates following road construction.

Fill slope erosion was also measured by a complete survey of rills and gullies. Sediment movement downslope was described as a distance of transport and fate of the sediment. While this technique does not include quantities of interrill erosion, it does allow estimation of fill slope erosion along any specific length of the road.

The road through subdrainage 16 has 731 feet of fill slopes and 755 feet of cut slopes that could contribute sediment to the C monitoring station. However, 550 feet of the fill slopes, adjacent to the live water crossings, are protected with filter windrows. These filter windrows consist of logging slash and debris remaining from the clearing operation. Cull logs are "keyed" into the toe of the slope and slash is placed above the log on the lower one-half to two-thirds of the slope and tamped into the surface. This provides a filter of slash to trap eroded fill material and prevent downslope transport.

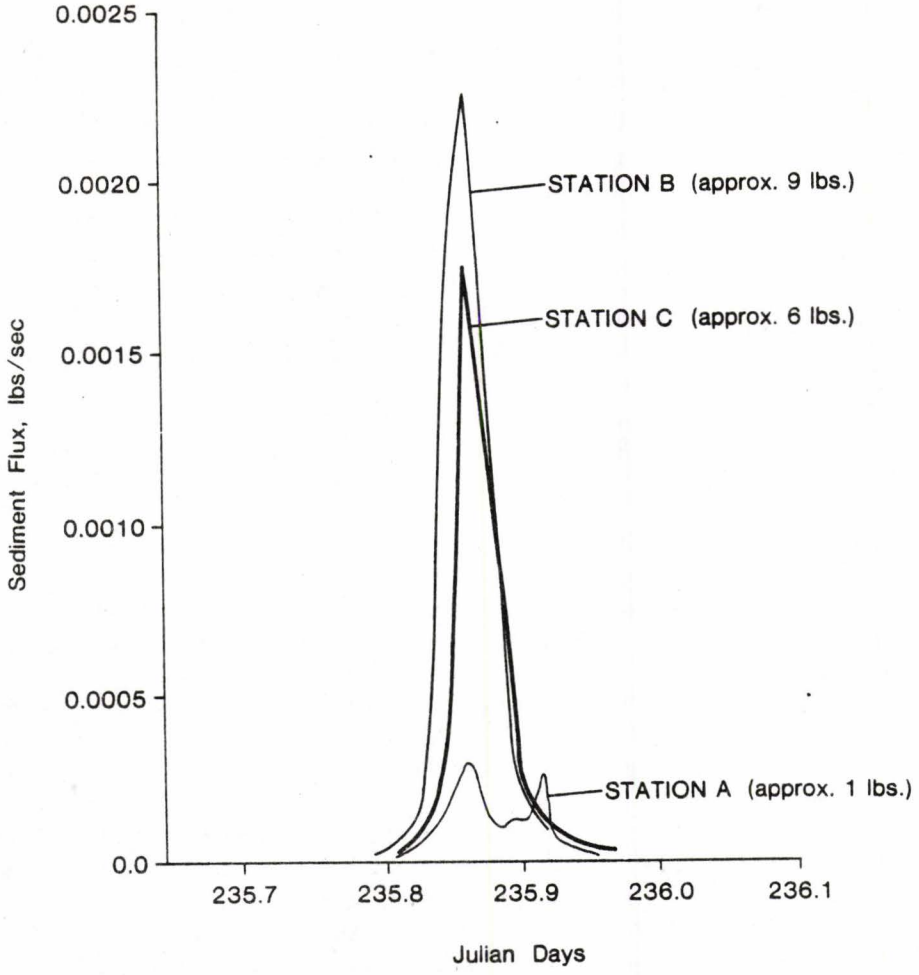

Figure 10. The sediment flux measured at the automatic sampling stations in subdrainage 16 during a thunderstorm on July 23, 1979.

During the first summer and fall after construction approximately 1,000-1,500 lbs of material eroded from cut slopes in subdrainage 16 compared to 25,000-40,000 lbs from the fill slopes. The filter windrows captured all of the eroded fill material. On those fill slopes not protected with filter windrows, none of the eroded material reached live water. Thus, any road derived sediment reaching the C station during rain events was contributed from the cut slopes, ditches, and/or some portion of the road surface. Near the end of the construction season the cuts and fills were hydroseeded and mulched.

In the spring of 1979, cut slope erosion increased dramatically to 26,000 lbs in subdrainage 16. This is attributed to sloughing of loose material during saturated or near saturated conditions during snowmelt. Fill slope erosion was relatively small in comparison, only 1,600 lbs. For this snowmelt period, all of the eroded fill material was deposited in the filter windrows. Thus, road derived sediments were all routed to the stream via the ditch system.

The second summer and fall following construction cut slope erosion amounted to 10,000 lbs, a substantial increase from the previous summer. However, fill slopes were less than the previous summer by a factor of 5, totalling 7,000 lbs. There was one breach in the filter windrows but none of the material was transported to the stream.

It becomes obvious that (1) the magnitudes of on-site erosion are much greater (in the order of 10^2) than the amount of stream sedimentation that can be attributed to the roads, (2) fill erosion is very high during the first few intense storms following construction and becomes less susceptible to erosion during subsequent rain events, (3) cut slope erosion is much greater during the spring snowmelt event than during rainstorm events and (4) filter windrows provide an effective means of controlling sediment movement from fill slopes at least during the first 1 1/2 years following construction.

Roads constructed in 1978 had filter windrows on 1,220 feet of road fill. Both the volumes of material moving through the windrows and transport distance below the windrows was held to a minimum (Figure 11). The downslope transport distance of material from unprotected fills was one to two orders of magnitude greater than from windrowed fills. In watershed 16 there probably would have been a substantial increase in the sediment flux at the C station during intense rain storms or periods of rapid snowmelt, if a filter windrow was not present. The long term effectiveness of the windrows will be evaluated. Their performance will depend in part on their storage capacity, the rate of stabilization of the fills, the occurrence of extreme events, and the long term stability of the filter windrows.

SUMMARY AND CONCLUSIONS

The results indicate that the roads have had a minimal impact on the Main Fork of Horse Creek to date. Only small amounts of road derived sediment, predominately suspended sediment, were evident at the mouths of the subdrainages. However, under different climatic conditions, the results could have been substantially different.

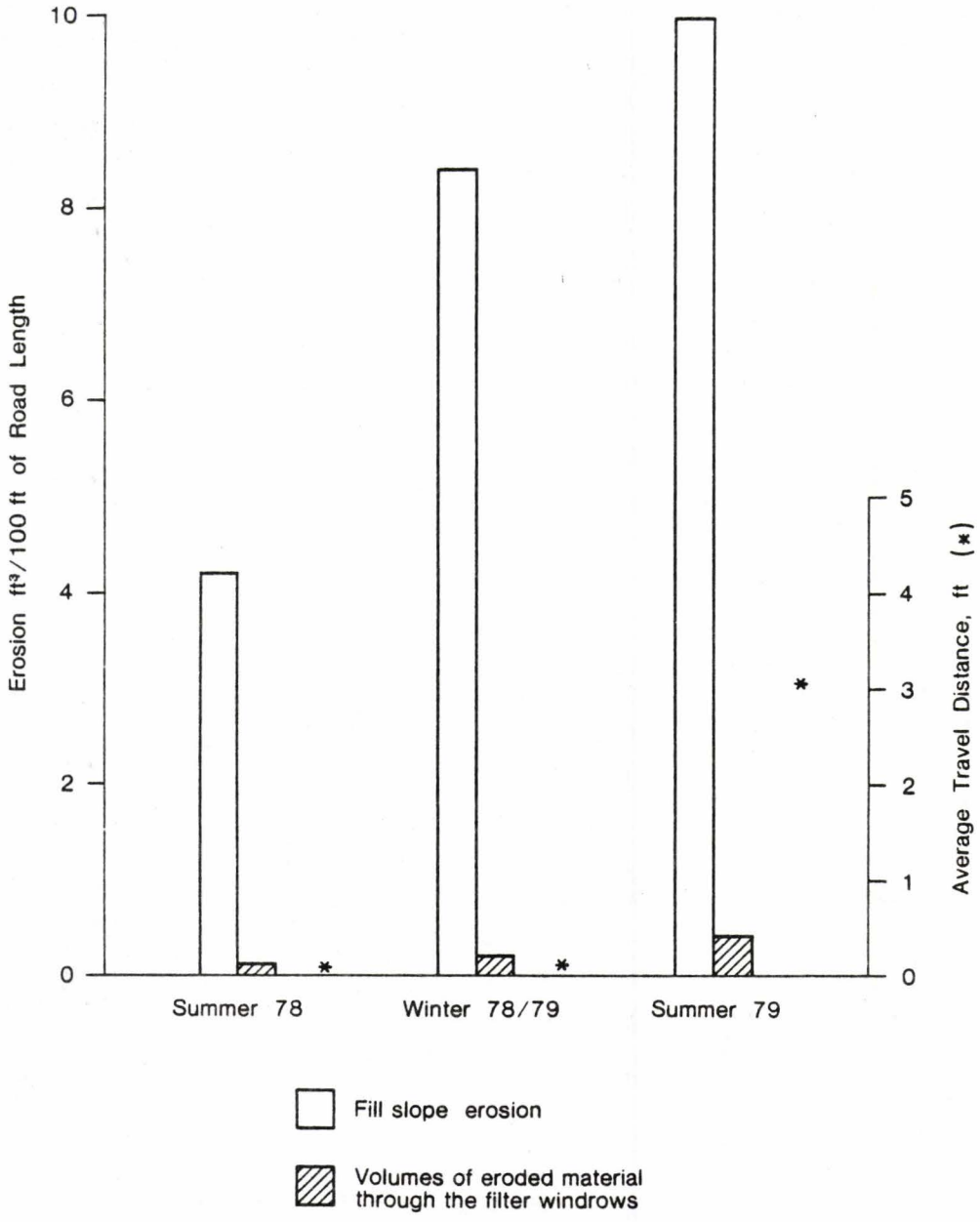

Figure 11. Volumes of fill slope erosion and material transported through the filter windrows and the distance of material transported downslope.

During pioneering and culvert installation and during thunderstorm activity the first summer following construction considerable fluxes of road derived sediment reached the stream channel. Although measured sediment concentrations are high, total amounts added to the channel are relatively small when compared to the natural annual sediment production.

During the first snowmelt period the flux of sediment past the B and C stations was appreciably higher than the flux measured at the A station. The filter windrows prevented fill material from being transported downslope; therefore, the primary source of the sediment was from the road surface, ditch system and cut slopes.

Sediment transported from the road prism is being stored in the channels. The flux of sediment past the B station was considerably higher than the flux measured at the C station. Similarly, the flux past the C station was considerably higher than at the subdrainage mouth. Channel transect measurements substantiate channel aggradation due to the storage of road derived sediments. These measurements indicate that material is predominately being stored in the lower reaches of the channel system in the subdrainages.

During the second summer, following construction, the inputs of road derived sediment were considerably reduced. This is partially attributed to the revegetation of the fill slopes and the armouring of the ditches. Again, this sediment is being stored in the channel system.

Inputs of sediment to the streams can be significantly reduced by the construction of filter windrows on the fill slopes. Virtually no sediment was contributed to the C station from windrowed fills. Another technique to reduce sediment contributions to streams is the dewatering of the site during culvert installation. Both the duration of the effect and the total amount of sediment produced were significantly less than the sediment contributed during installation of culverts "in the wet."

We are continuing to monitor the erosion and sedimentation processes in Horse Creek. Intuitively we feel that these streams are becoming loaded with sediment and a single extreme event could flush the channels and perhaps affect the physical and biological character of the Main Fork of Horse Creek. Continued refinement of our sampling and measuring techniques will hopefully allow us to use the data to adapt existing models or to develop new models for extrapolating erosion and sediment information.

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SECTION 10

EFFECT OF FOREST ROADS ON STREAM CHANNELS AND AQUATIC POPULATIONS

INTRODUCTION

When the Horse Creek watersheds were chosen in 1965, primarily as sites to measure natural and disturbed rates of sediment transport, there was less interest in aquatic organism responses to sediment than in physical sedimentation processes. In recent years there has been a growing concern over the effects of sediment on aquatic organisms. Surveys of fish, amphibians, invertebrates, periphyton, and habitat conditions were taken throughout the watersheds during 1978 and 1979. These measurements will be continued to monitor aquatic organism communities and stream habitats after road construction and during logging which is scheduled to start in 1981.

Results of this study are presented in two parts: Part I describes baseline conditions of aquatic organisms and habitat in Horse Creek before road building; Part II analyzes aquatic insect populations and sediment deposition in stream channels during road building.

Part I

Densities and Distributions of

Aquatic Organisms in Horse Creek

Fish

Horse Creek flows into Meadow Creek four miles above the confluence of Meadow Creek and the Selway River. In 1975 and 1976 the U.S. Forest Service, in cooperation with the Idaho Department of Fish and Game, conducted fish habitat surveys in the Meadow Creek drainage (Martin 1976). Horse Creek was not included in the survey but Meadow Creek, at the mouth of Horse Creek, was surveyed. Martin noted that 62 percent of the anadromous fish spawning habitat in Meadow Creek was of good quality. Results of his survey near the mouth of Horse Creek concluded that there was excellent quality spawning gravel for chinook salmon and steelhead below the mouth of Horse Creek. Physical and biological parameters were of good to excellent condition and were similar above and below the mouth of Horse Creek. There was no silt, and 100 percent of the spawning habitat above and below the mouth was of good quality.

There is no record of previous fish collections in Horse Creek and little was known about them before this study. Reports from anglers indicated a population of cutthroat trout. However, Horse Creek has a series of waterfalls above its mouth which are a barrier to all fish, anadromous and resident, moving up from Meadow Creek. So, our first questions to answer were what are the fish in Horse Creek, and how did they get there?

In the summers of 1978 and 1979, we electrofished sections of the East and Main Forks of Horse Creek using a Coefelt portable backpack shocker. Three consecutive 50-yard sections of Horse Creek above the confluence of each north slope watershed (watersheds 2, 4, 6, 8, 10, 12, 14, 16 and 18) were shocked (Figure 1). Also, three 50-yard sections were shocked above the main sediment dams on the Main and East Forks of Horse Creek and immediately above the confluence of these two streams. All fish were measured for length and the numbers collected were recorded. In 1978 a few large fish were preserved and returned to the University of Idaho for more exact species identification.

Rainbow trout (Salmo gardneri) was the only species of fish we found in Horse Creek. Dr. Richard Wallace, University of Idaho, identified these fish and believes they are descendants from hatchery stock. His studies of rainbow trout indicate that there are two strains of rainbow in the western United States. One is a coastal rainbow in Pacific Coast streams from California into Canada. The other is an inland rainbow which makes up the native rainbow and steelhead of Idaho. The original broodstock for Idaho fish hatcheries was brought in from the McCleod River Hatchery in California. These trout were of the coastal rainbow variety and consequently the strain which has since been planted throughout Idaho.

Horse Creek trout have morphological characteristics of hatchery trout indicating that their descendants had been planted. If they had descended from trout which had moved up from Meadow Creek and the Selway River (possibly the series of falls on Horse Creek was not always a barrier), they would show native rainbow-steelhead characteristics.

How long have these trout been in Horse Creek? We have been unable to find a record of any state agency planting in Horse Creek. The road from Selway Falls to Elk City was built in the 1930's, but horse and mule trails were in the area much before that time. Hatchery trout could have been carried in and planted by anyone as early as the late 1800's.

This isolated single species of fish may be good for study purposes. We are eventually going to watch for changes in the fish population of Horse Creek with road building and logging of tributary watersheds. One species may better reflect the effects of sediment than several species which are competing interspecifically as well as intraspecifically for food, cover, and space. With an isolated population we do not have to be concerned with immigrators from the downstream populations.

We electrofished a total stream length of 2100 yards and collected 129 fish or an average of 61 fish per 1000 yards of stream in 1978. We collected 281 fish (134 fish per 1000 yards) in 1979. These are very low sampling densities compared to streams of similar size such as Crocker and Yakus Creeks in the Clearwater drainage which average approximately 500 rainbow trout per 1000 yards of stream using the same shocking techniques (Falter et al. 1976b). The Horse Creek fish averaged approximately 10.2 cm during 1978 and 12.1 cm in 1979 and ranged from 5.5 cm to 26.5 cm in length (Figure 2).

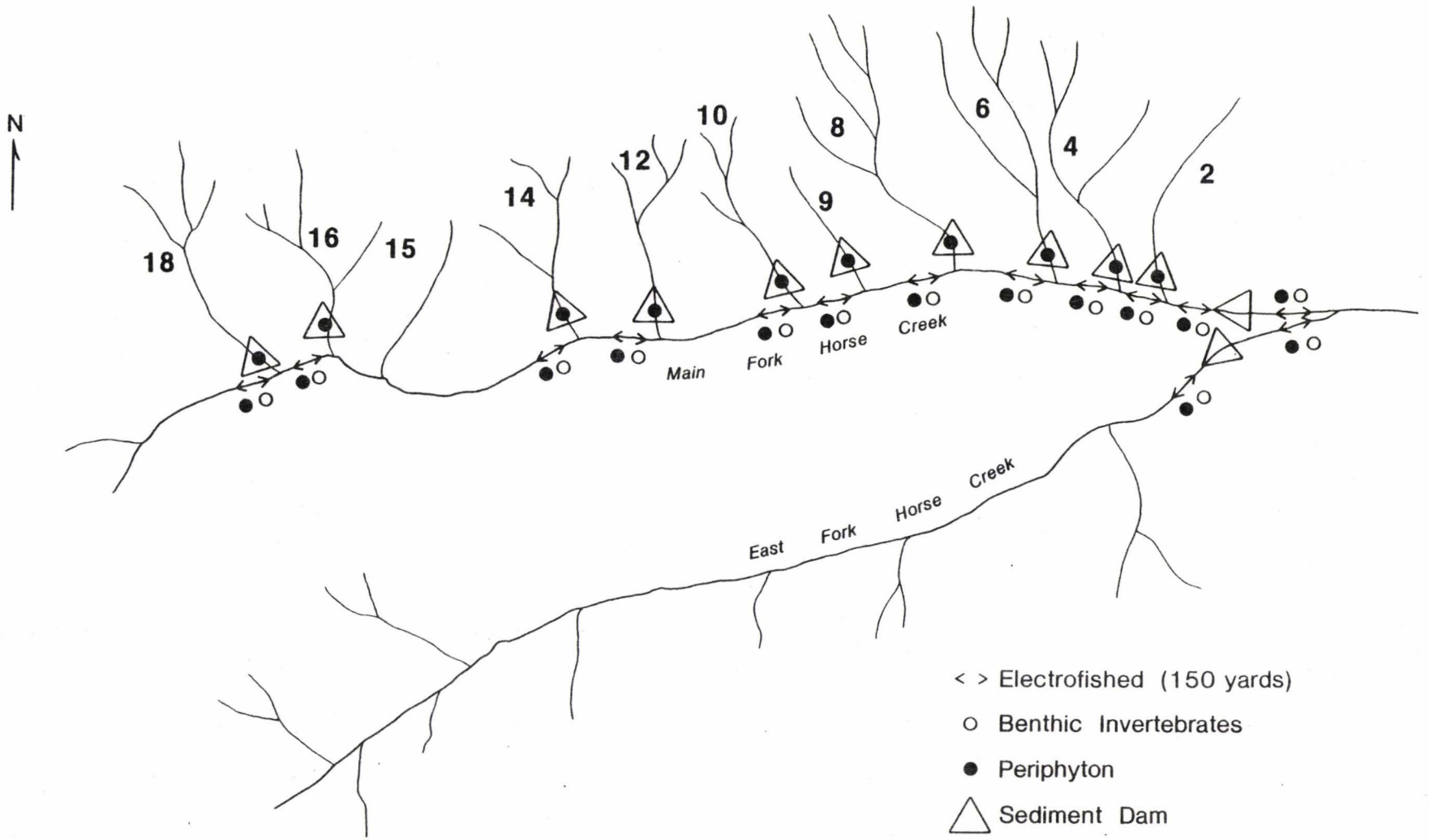

Figure 1. Sampling locations in Horse Creek.

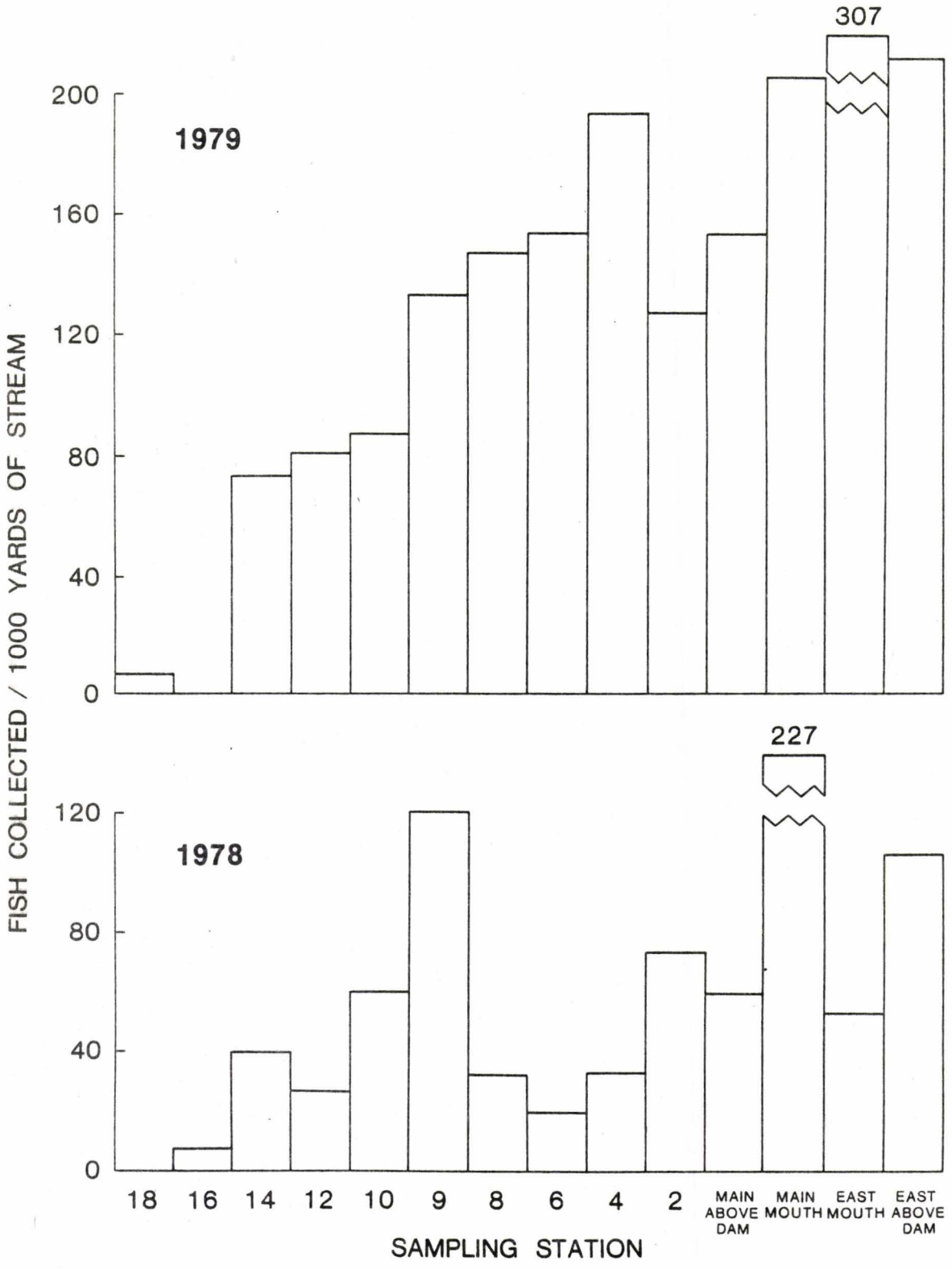

Figure 2. Number of rainbow trout collected throughout the Main and East Forks of Horse Creek, 1978 and 1979.

The greatest number of rainbow trout collected occurred in both the Main Fork and East Fork above their confluence (Figure 2). The number of fish collected in the Main Fork dropped off above the mouth of watershed 16 and only one fish was collected above that point each year. In this upper reach of Horse Creek there are very few pools and the stream is shallow and narrow.

During August 1978 and 1979, we also measured stream substrate compositions in the two forks of Horse Creek in the same areas where fish were shocked. Measurements were made by stretching a 20-foot tape diagonally across the stream. The predominant substrate size was estimated for each foot of the stream for the length of the tape. Five of these 20-foot transects were surveyed for each of the 14 fish-sampling areas. Six substrate size classes were chosen: bedrock, boulder (> 12"), rubble (3-11.9"), gravel (.19-2.9"), fines (<.18"), and debris (organic material, logs, roots, etc.). (Tables 1 and 2).

The highest concentration of fines were 24 and 38 percent respectively, in the East and Main Forks below the large sediment dams on these two streams in 1978. In contrast, the substrate immediately above these dams contained 10 percent fines in the East Fork and 4 percent fines in the Main Fork. These dams are flushed of sediment annually, and this high percentage of sediment below the dams before flushing indicates that not all fines are washed out during spring runoffs.

In 1979 (Table 2) concentrations of fines were very high from the mouths of watershed 9 upstream beyond the mouth of watershed 18. The high concentrations of fines (35 percent) above the mouth of watershed 18 indicate that these concentrations of fines are natural. Apparently, annual variations in sediment storage in the Main Horse Creek are high as a natural condition.

Table 1.--Size distribution of channel material in the Main and East Forks of Horse Creek, August 1978.

Location	Percent in Each Size Class				
	Boulder (>12")	Rubble (3-11.9")	Gravel (.19-2.9")	Fines (<.18")	Debris (organic material)
East above dam	14	49	25	10	2
East mouth	2	11	63	24*	0
Main mouth	0	14	45	38*	3
Main above dam	17	51	28	4	0
Main above mouth of watershed 2	24	37	34	4	1
Main above mouth of watershed 4	26	34	38	1	0
Main above mouth of watershed 6	4	31	51	13	1
Main above mouth of watershed 8	33	31	30	4	2
Main above mouth of watershed 9	2	12	69	8	9
Main above mouth of watershed 10	1	19	62	17	1
Main above mouth of watershed 12	0	2	80	16	2
Main above mouth of watershed 14	2	6	79	9	4
Main above mouth of watershed 16	8	13	57	16	6
Main above mouth of watershed 18	2	7	62	19	10
$\bar{X}$	9.6	22.6	51.7	13.2	2.9

* Concentration of fines high enough to possibly decrease fish fry survival.

Table 2.--Size distribution of channel material in the Main and East Forks of Horse Creek, August 1979.

Location	Percent in Each Size Class				
	Boulder (>12")	Rubble (3-11.9")	Gravel (.19-2.9")	Fines (<.18")	Debris (organic material)
East above dam	9	55	34	2	0
East mouth	0	5	76	19*	0
Main mouth	0	12	62	26*	0
Main above dam	6	59	19	15	1
Main above mouth of watershed 2	25	57	16	2	0
Main above mouth of watershed 4	28	41	28	3	0
Main above mouth of watershed 6	14	36	32	14	4
Main above mouth of watershed 8	31	48	13	5	3
Main above mouth of watershed 9	1	25	39	23*	12
Main above mouth of watershed 10	0	15	49	35*	1
Main above mouth of watershed 12	0	5	71	20*	4
Main above mouth of watershed 14	3	10	64	22*	1
Main above mouth of watershed 16	9	14	44	23*	10
Main above mouth of watershed 18	0	8	37	35*	20
$\bar{X}$	9.0	27.8	41.7	17.4	4.0

* Concentration of fines high enough to possibly decrease fish fry survival.

There appears to be no relationship between percent fines in stream substrate (within ranges found in Horse Creek) and numbers of fish collected in different reaches of Horse Creek. Concentrations of fines averaged 26 percent in the Main Horse Creek from the mouth of watershed 9 upstream beyond the mouth of watershed 18 in 1979 (Table 2). Fines made up only 14 percent of the substrate in this stream reach during 1978. Number of fish collected did not appear to be reduced by this increase in fines. In fact, they increased from an average of 42 fish per 1000 yards of stream in 1978 to 63 fish per 1000 yards collected in 1979 upstream beyond the mouth of watershed 9 (Table 3).

The Main and East Fork sediment dams were flushed in August 1978 after fish were sampled. However, in 1979 these dams were flushed before fish were surveyed. Collected rainbow trout numbered 227 fish per 1000 yards in 1978 before flushing and 206 in 1979 in the Main below the dam after flushing. Numbers of fish collected were 53 fish per 1000 yards in 1978 before flushing and 307 in 1979 after flushing below the East Fork dam. This indicates that fish do not move out of these areas below dams immediately after flushing even though concentrations of suspended sediment and bedload must be extremely high.

The fish which were preserved for identification were also aged, using an otolith ring count (Lawler and McRae 1961). These seven fish were the largest fish shocked in 1978 and ranged in length from 6.3-8.7 inches (16-22 cm). All of these fish were four years old (IV^{+}). Four-year-old fish which are not larger than 9 inches are slow growing compared to rainbow trout from other streams. The average length of four-year-old rainbow from streams in Montana and Idaho is approximately 14-15 inches (Calhoun 1966). Slow growth in Horse Creek may be a result of many factors such as water temperature, low primary production (algae), and low secondary production (invertebrates). Large fish in Horse Creek have only insects and smaller rainbow trout as major food sources since there are not other fish species available for forage (Figure 3).

Table 3.--Fish collected and size estimates of rainbow trout (Salmo gardneri) in the East and Main Forks of Horse Creek, 1978 and 1979

Location	Trout collected/1000 yds 1978	1979	Average size (cm) 1978	1979
East above dam	107	213	9.4	9.5
East mouth	53	307	11.7	10.1
Main mouth	227	206	9.5	12.0
Main above dam	60	153	8.3	12.1
Main above mouth of watershed 2	73	126	8.0	11.1
Main above mouth of watershed 4	33	193	13.6	11.5
Main above mouth of watershed 6	20	153	17.2	15.7
Main above mouth of watershed 8	33	147	15.5	13.7
Main above mouth of watershed 9	120	133	8.7	12.6
Main above mouth of watershed 10	60	87	11.1	12.5
Main above mouth of watershed 12	27	80	16.3	14.2
Main above mouth of watershed 14	40	73	11.5	13.1
Main above mouth of watershed 16	7	0	16.2	--
Main above mouth of watershed 18	0	7	--	17.0
$\bar{X}$	61	134	10.2	12.1

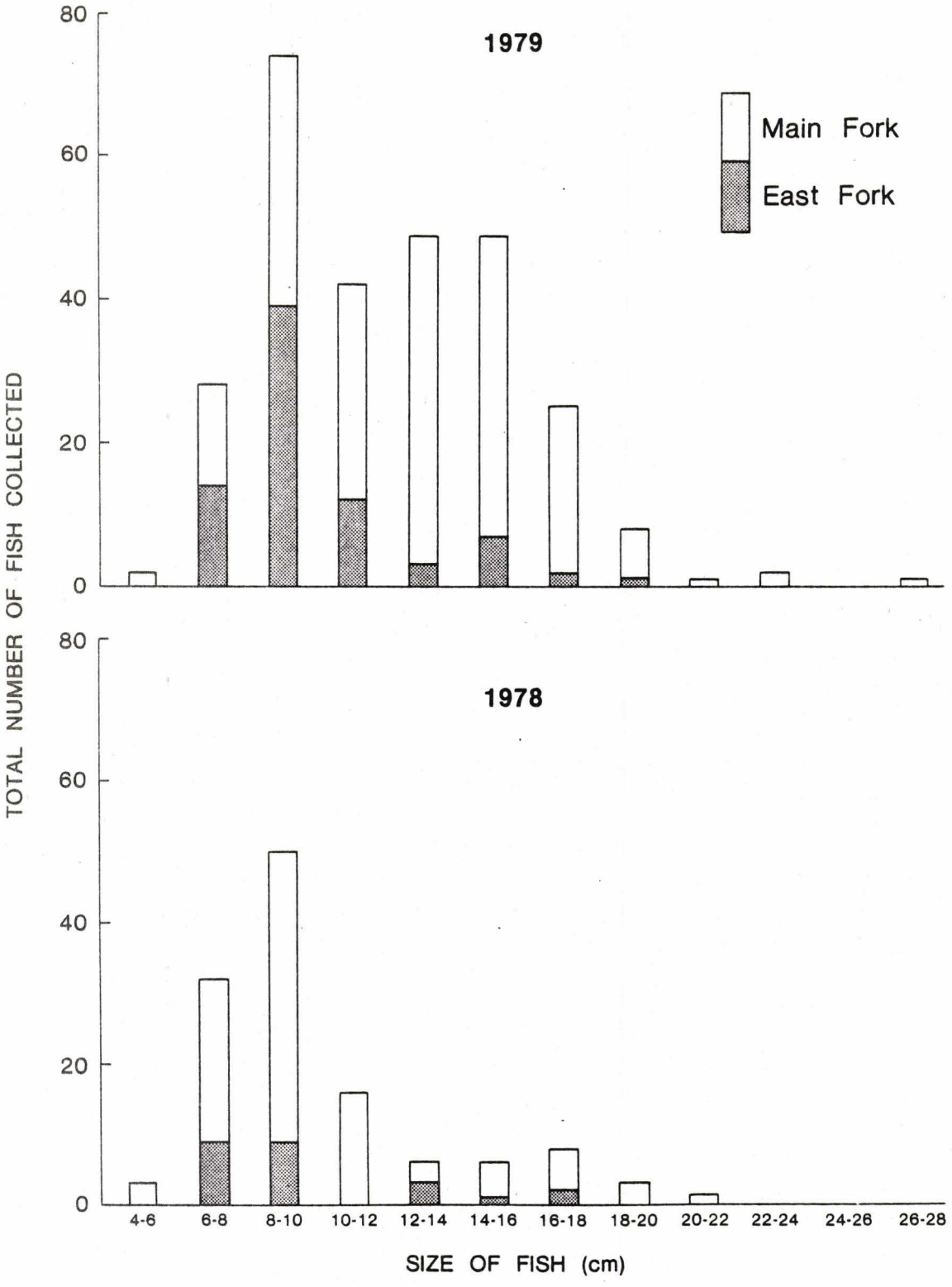

Figure 3. Size distribution of all rainbow trout collected in the Main and East Forks of Horse Creek, 1978 and 1979.

Amphibians

The Horse Creek drainage is inhabited by two relatively unique species of amphibians: the tailed frog (Ascaphus truei) and the Pacific giant salamander (Dicamptodon ensatus). Both of these animals have narrow habitat requirements and are only found in cold, fast mountain streams of the Northwest. They are not widespread and never abundant. It is possible that these amphibians may be sensitive to sedimentation and/or warming waters and may be indicators of stream changes.

The tailed frog is one of two species of frogs in the world which exhibits internal fertilization by means of a "tail" used as a penis. Internal fertilization is an adaptation to cold, fast-flowing stream habitats. These frogs are not found in streams which warm to more than 16-18° C, and temperatures approaching 20-22° are lethal (Metter 1963).

Adult frogs feed exclusively on insects, and tadpoles (called bell toads in this species) eat periphyton (attached algae). Breeding occurs from April through September and the frogs are dormant during the rest of the year. These frogs are not prolific breeders and produce only 25-50 eggs/female as compared to 6,000 and 20,000 eggs/female produced by leopard and bull frogs, respectively.

We have seen adult tailed frogs in both the Main and East Forks of Horse Creek and throughout all the north slope tributary watersheds. We collected adults in Horse Creek when we electrofished during the summers of 1978 and 1979. We collected an average of 121 adults/1000 yards of stream in 1978 and 125 adults/1000 yards in 1979. There was no obvious trend in distribution during these two years (Table 4).

Tailed frog larvae were collected in conjunction with insects using a Hess insect sampler. In the Main and East Forks, the larvae averaged 3.4/ft^2 in July and 2.6/ft^2 in September (Table 4). The highest density was 12.5 larvae/ft^2 in the Main above the mouth during July 1978. This was also the area where the highest numbers of fish were collected at that time. The Main dam was flushed of sediment during August 1978 and larvae numbers were 2.5/ft^2 in September. This was the section of Horse Creek which had high concentrations of fines (38%) in 1978, presumably due to the flushing of the Main sediment dam. Tailed frog densities averaged 3.9 and 1.7 larvae/ft^2 in the spring and fall of 1979. Distribution and numbers of tailed frog larvae were similar in 1978 and 1979 throughout the Main and East Forks of Horse Creek.

Table 4.--Tailed frog larvae (#/ft^2) and adults (#/1000 yds) (Ascaphus truei) collected in the Main and East Forks of Horse Creek, 1978 and 1979.

Location	Larvae collected/ft^2				Adults collected/1000 yds	
	Spring		Fall		Summer	
	1978	1979	1978	1979	1978	1979
East above dam	2.5	5.0	5.0	2.3	193	160
East mouth	5.5	2.3	1.5	0.3	60	133
Main mouth	12.5	8.7	2.5	2.3	47	27
Main above dam	3.0	2.3	4.3	0.3	33	67
Main above mouth of watershed 2	7.0	3.7	2.0	1.0	253	60
Main above mouth of watershed 4	0.5	7.0	3.5	2.3	73	180
Main above mouth of watershed 6	3.0	1.0	2.0	0.7	140	120
Main above mouth of watershed 8	1.5	4.7	2.0	1.0	140	253
Main above mouth of watershed 9	1.0	3.0	4.8	2.3	107	253
Main above mouth of watershed 10	2.0	2.7	2.3	1.7	113	127
Main above mouth of watershed 12	1.5	4.0	0.8	2.7	60	120
Main above mouth of watershed 14	3.0	4.0	2.0	5.0	128	113
Main above mouth of watershed 16	1.0	4.3	2.5	1.3	140	87
Main above mouth of watershed 18	4.0	2.0	2.0	1.0	213	47
$\bar{X}$	3.4	3.9	2.6	1.7	121	125

North slope watersheds (6, 8, 14 and 16) were sampled for tailed frog larvae in six reaches of each stream in 1978 (Table 5). These reaches were chosen for sediment aggradation-degradation measurements in another phase of the study. Watersheds 10 and 12 were also sampled in 1979. Larvae densities in these watersheds averaged less than 1.0/ft^2 in 1978 and 1979, much less than in the Main and East Fork. The upstream reaches, which are mostly first order streams, had very few tailed frog larvae. Apparently, larvae require at least second order streams while adults range throughout the watersheds.

The Pacific giant salamander was collected in the Main and East Forks of Horse Creek during electrofishing. Only 10 larvae were found throughout the 2100 yards of stream sampled in 1978 and 23 were collected in 1979. Distribution was relatively even and the range extended from the East Fork above the dam through watershed 18 on the Main Horse Creek.

The Pacific giant salamander is the largest salamander in Idaho and can grow to 12 inches in length. The larvae spend at least 2 years in streams and then can metamorphose into adults or retain larval characteristics (neoteny) and reproduce in the stream. Larvae feed on stream insects but adults eat a wide range of food from frogs to small mammals such as mice and shrews. Adults are active on land and are even known to climb trees. Little is known about the salamander's habitat requirements or its reaction to changing stream conditions.

Periphyton

Periphyton, or attached algae, is a large source of primary production in streams. It is often the only instream source of organic matter (plant material washed into the stream is another source) available for higher tropic levels. In Horse Creek it is a food source for many insect species, amphibian larvae, and benthic invertebrates. Periphyton is probably the first community to respond to water quality changes, especially nutrients, temperature, and light availability (turbidity).

We measured periphyton production using glass slides suspended in racks in the Horse Creek streams. The algae grows on the slides much like it does on rocks and can be dried and weighed quantitatively.

Table 5.--Population densities (#/ft^2) of tailed frog larvae (Ascaphus treui) in first and second order tributaries to Horse Creek, 1978 and 1979

Location	North Slope Watersheds 16 Spring	16 Fall	14 Spring	14 Fall	8 Spring	8 Fall	6 Spring	6 Fall
1978								
1st Order								
1	0	0	0	2.4	0	0	-	0
2	0	0	0	0	0	0		
3	0	0	0	0.9	0	0		
2nd Order								
4	0	0	0	0	0	0		
5	0.3	0.5	0.3	0	1.0	0	-	0.9
6	0	0.7	1.7	0	1.0	0.9		
1979								
1st Order								
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	-	-
3	0	0	0	0	0	0	-	-
2nd Order								
4	1.0	0.3	0.7	0	0.7	0	-	-
5	0.3	0.7	0	0	0	1.0	3.3	0.3
6	2.3	0.3	3.0	2.7	0.3	1.0	-	-

Location	10 Spring	10 Fall	12 Spring	12 Fall
1st Order				
1	0	0	0	0
2	0	0	0	0
3	0	0	0.3	0
2nd Order				
4	0	0	0.3	0
5	0	0.3	0	0
6	1.3	0.6	0.7	2.3

To measure production in the shallow north slop drainages, we suspended the glass slides in the sediment ponds at the mouths of each drainage. The biomass over a 30-day incubation in June-July 1978 was 973 mg dry-wt/m^2 averaged over all ten drainages (Figure 4). Production during this same period in 1979 averaged 589 mg dry-wt/m^2. There appears to be more production in the upstream drainages than in the downstream drainages. A late summer incubation was not done in 1978 because the dams were flushed during that time. The late summer production in 1979 averaged 2865 mg dry-wt/m^2.

Early- and late-summer periphyton incubations were done in the Main and East Forks of Horse Creek. Production averaged 1200 and 1289 mg dry-wt/m^2 for the two runs (Table 6). This indicates that production does not change significantly through the summer season and may not be influenced by temperature or light but may be limited by nutrients. However, production average 1334 and 3147 mg dry-wt/m^2 for incubations in the spring and fall of 1979. We are unable to explain the high periphyton production levels throughout the study area in the fall of 1979. These production levels are low compared to similar cold water streams in the Gallatin and Madison watersheds in Montana (Hayman and King 1977) which average 2050 mg/m^2. Levels are very low compared to high nutrient streams such as the Snake River which averages 5500 mg/m^2 (Falter et al. 1976a) (Figures 5 and 6).

Aquatic Insects

Aquatic macroinvertebrate samples were collected on the Main and East Forks of Horse Creek using a 0.5 square-foot modified Hess Sampler. Two samples, each consisting of three subsamples, were taken at each site. Site locations correspond to those used in the fishery and substrate studies. The samples, taken in early July and September, 1978 and 1979, were preserved in 70 percent ethyl alcohol.

Aquatic macroinvertebrates were analyzed for species composition, population levels, number of species, Shannon-Weaver species diversity, and equitability. Keys used in the identification included Pennak 1953, Jenson 1966, Smith 1969a and 1968b, Gaufin et al., 1972, and Wiggins 1977.

Species diversity was calculated using the Shannon-Weaver index Lloyd et al., 1968). Chironomids, often unidentifiable to species, were excluded from calculation. The index is used as an indicator of community stability, and hence the degree of community disturbance. The index examines the number of species and the distribution of individuals within the species. The diversity value is zero when all individuals are of one species and reaches a maximum when all individuals belong to different species.

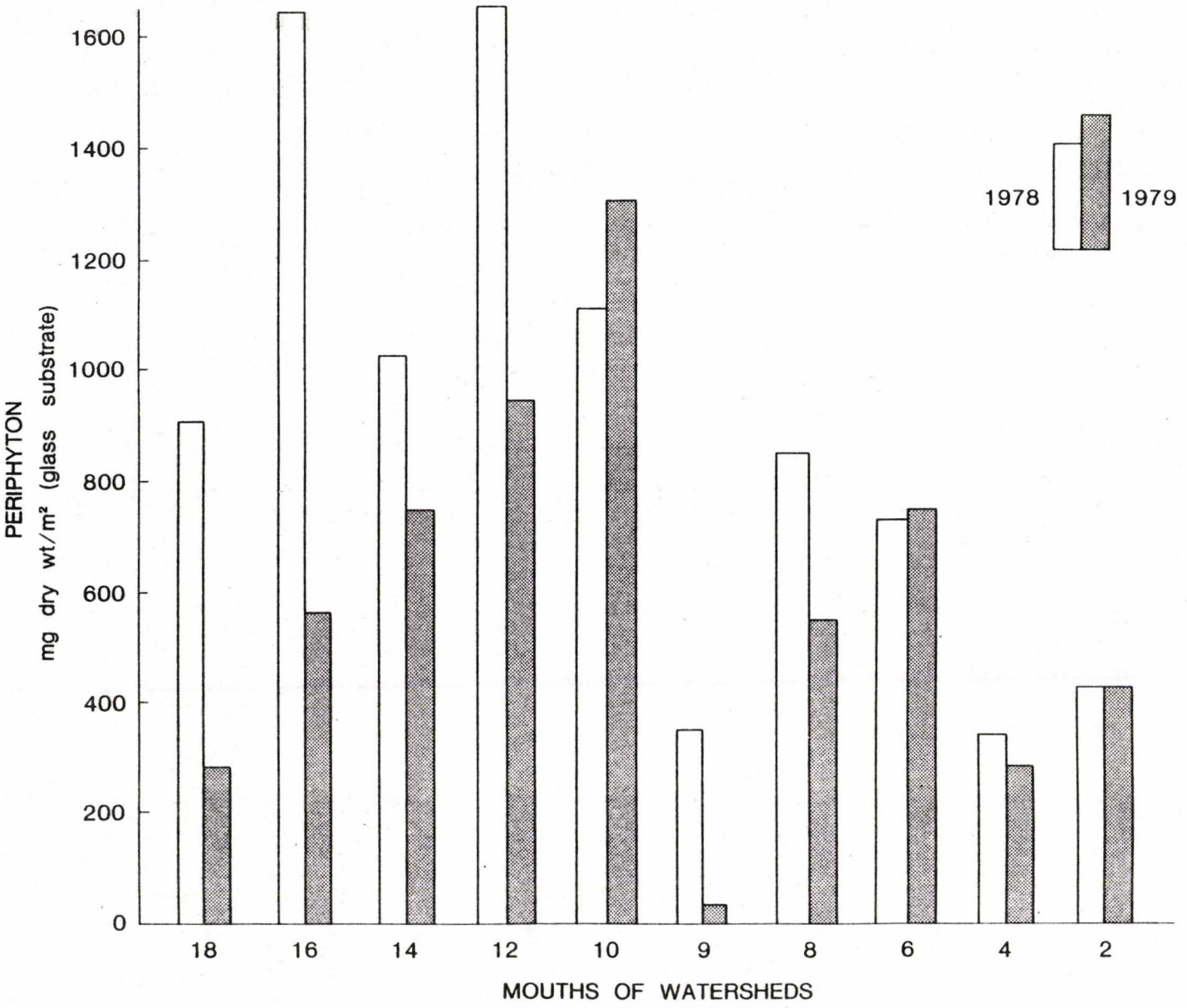

Figure 4. Periphyton production during June 28 to July 27, 1978 and 1979 (30 day incubation) in north side Horse Creek drainage sediment dams.

Table 6.--Periphyton biomass production (mg dry wt/m^2) in the Main and East Forks of Horse Creek, June-August, 1978 and 1979.

Location	1978 June 28-July 27	1979 June 27-July 26	1978 July 27-Aug 30	1979 July 26-Aug 29
East above dam	1966	1320	1602	4545
East mouth	754	637	1593	1357
Main Mouth	1636	1703	2356	2340
Main above dam	1915	2542	610	6029
Main above mouth of 2	1466	1029	602	3790
Main above mouth of 4	--	1678	3653	5320
Main above mouth of 6	534	1037	1331	2015
Main above mouth of 8	593	1741	322	3626
Main above mouth of 9	966	534	703	3284
Main above mouth of 10	2161	2487	906	3149
Main above mouth of 12	1492	1619	1127	2167
Main above mouth of 14	669	1134	1636	1223
Main above mouth of 16	559	780	1441	1547
Main above mouth of 18	890	434	169	3668
$\bar{X}$	1200	1334	1289	3147
Watershed dams 2	441	422	--	1201
Watershed dams 4	373	299	--	3356
Watershed dams 6	771	755	--	5080
Watershed dams 8	958	552	--	2201
Watershed dams 9	381	25	--	3419
Watershed dams 10	1153	1307	--	3145
Watershed dams 12	1856	957	--	2580
Watershed dams 14	1042	750	--	3052
Watershed dams 16	1898	544	--	4047
Watershed dams 18	856	278	--	1572
$\bar{X}$	973	589	--	2865

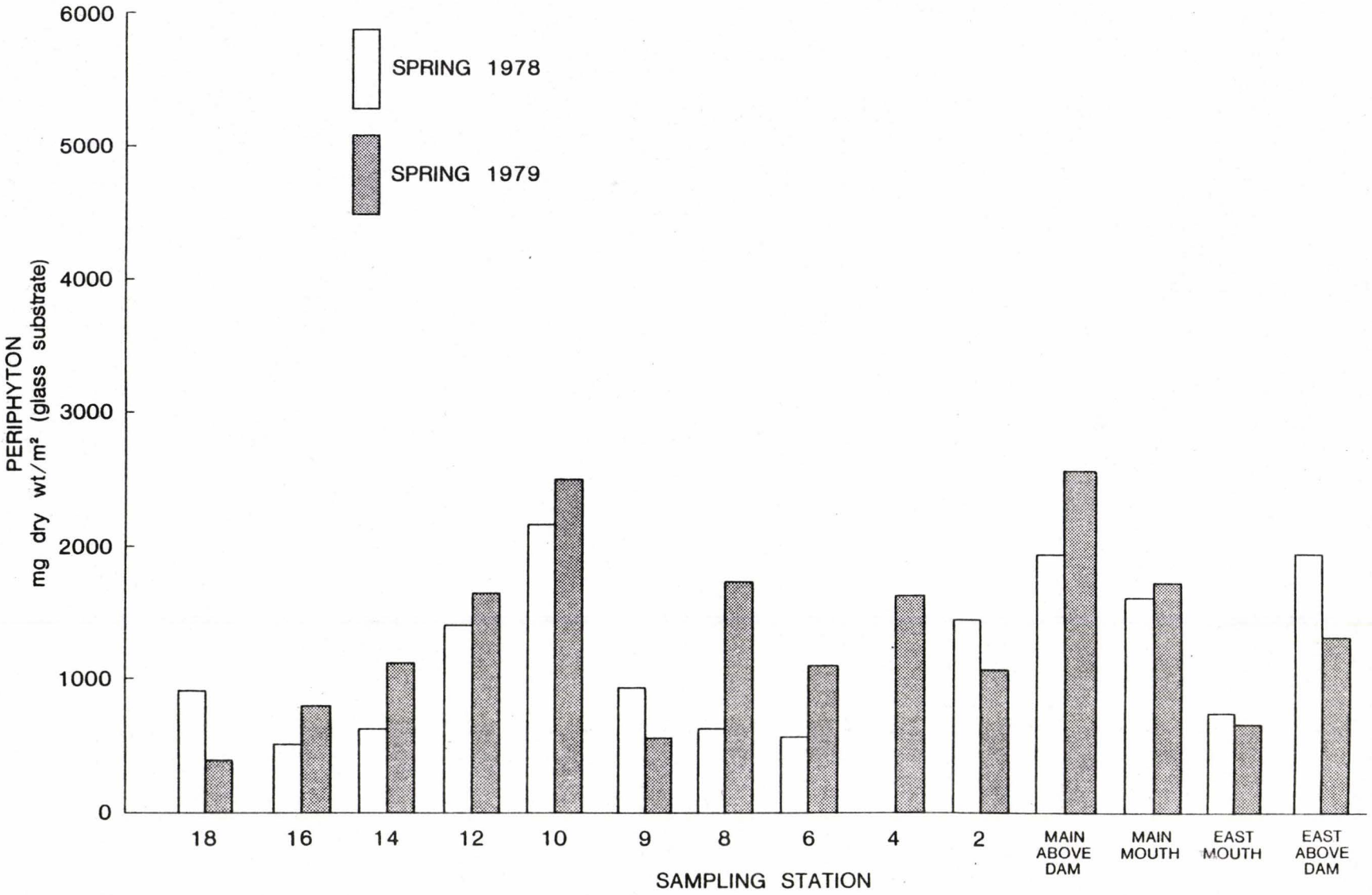

Figure 5. Periphyton biomass production on the Main and East Forks of Horse Creek during June 28 to July 27, 1978 and June 27 to July 26, 1979.

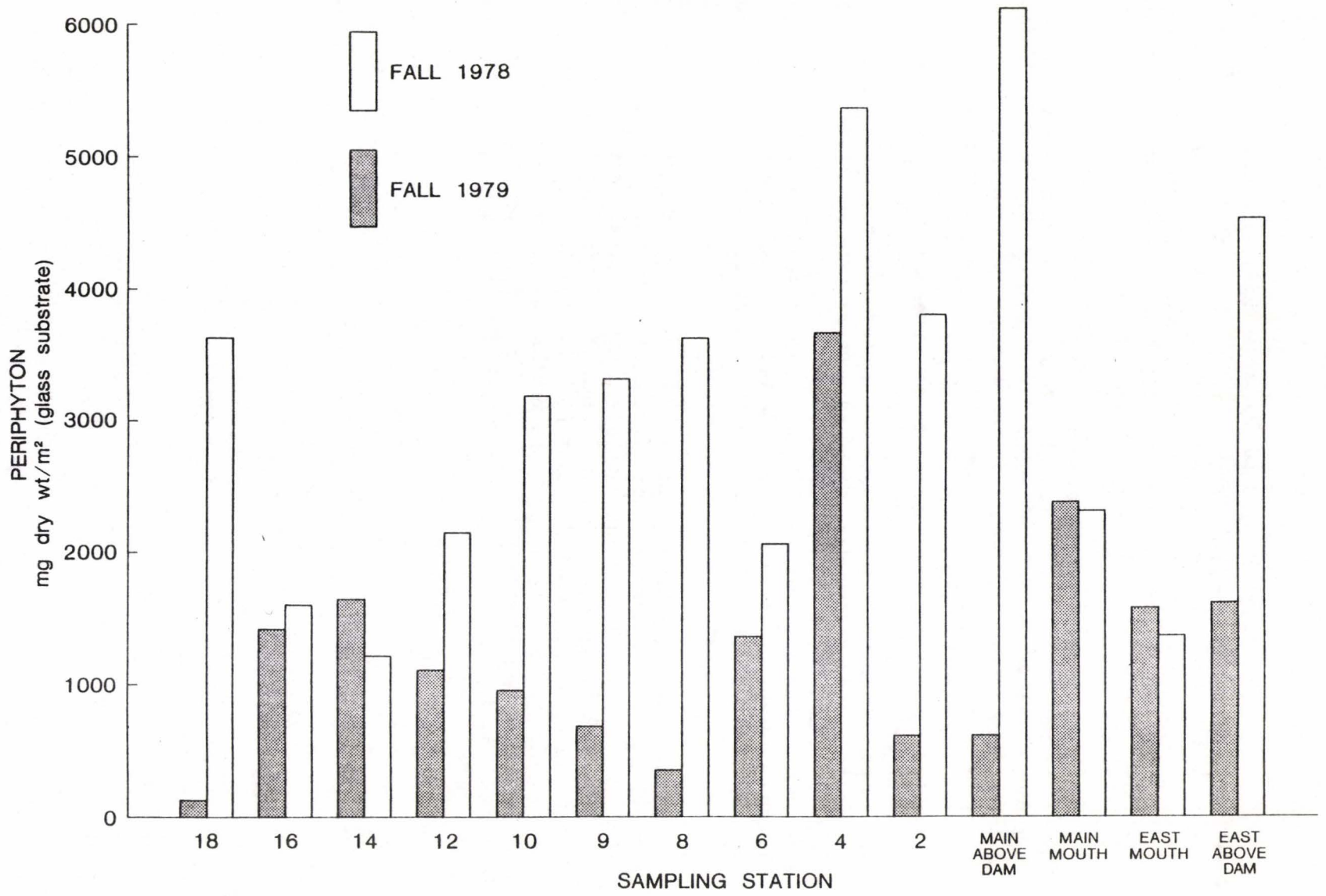

Figure 6. Periphyton biomass production on the Main and East Forks of Horse Creek during July 27 to August 30, 1978 and July 26 to August 29, 1979.

Equitability values (Lloyd and Ghelardi 1964), evaluating the distribution of individuals, compare the number of species to a theoretical maximum level. Values below 0.5 are considered indicative of community disturbance. In addition, values below 0.3 have been found when slight levels of degradation have little effect on diversity values (Environmental Protection Agency 1973).

The aquatic macroinvertebrate community in Horse Creek is represented primarily by five orders of insects: Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddisflies, Diptera (true flies), and Coleoptera (beetles). Other organisms were collected but their numbers were inconsequential in comparison to the aquatic insects.

Marked differences were observed in the community composition between upper and lower reaches of Horse Creek. During 1979, a change occurred at the mouth of watershed 12. Neothremma sp., Cinygmula sp., Arcynopteryx bradleyi and Peltoperla sp. became rare or altogether absent while riffle beetles and members of the genus Ephemerella became increasingly abundant. This shift in species composition was most pronounced in July. In 1978, this same pattern was observed, but the change occurred a little farther downstream near the mouth of watershed 9.

Species diversity and equitability values dropped in Lower Horse Creek during both September sampling periods from their July counterparts (Tables 7 and 8). During both years, the decrease was the greatest from the mouth of watershed 2 downstream. There was a large diversity drop at the Main Fork mouth and East Fork mouth (46% and 45%, respectively) during 1978. The drop at the mouths was not as severe in 1979 where decreases of 8 percent in the Main Fork and 15 percent in the East Fork were found. The Main and East Fork sediment dams were flushed in August both years.

Table 7.--Number of species, species diversity (Shannon-Weaver), equitability and standing crop (numbers/ft^2) in the Main and East Forks of Horse Creek, July and September 1978

Watershed	Number of Species		Species Diversity		Equitability		Standing Crop	
	July	Sept.	July	Sept.	July	Sept.	July	Sept.
18	14	17	3.22	3.08	0.94	0.70	28.5	41.0
16	19	20	3.58	3.07	0.91	0.59	29.5	55.0
14	21	16	3.38	3.20	0.71	0.81	50.5	32.0
12	30	24	3.84	3.41	0.69	0.63	84.0	61.0
10	25	17	3.52	3.48	0.66	0.94	44.5	18.5
9	23	25	3.57	3.14	0.74	0.50	47.0	87.5
8	23	30	3.74	3.78	0.84	0.66	66.0	56.0
6	17	22	3.49	3.37	0.95	0.67	51.5	50.5
4	22	18	3.63	2.56	0.81	0.45	52.0	42.0
2	20	22	3.80	2.66	1.00	0.40	43.0	58.5
Main above	14	17	3.35	3.39	1.00	0.88	25.0	40.4
Main mouth	28	17	3.95	2.12	0.80	0.34	61.5	46.0
East mouth	23	24	3.44	1.90	0.68	0.20	81.5	92.0
East above	20	22	3.59	2.95	0.87	0.49	63.5	80.0

Table 8.--Number of species, species diversity (Shannon-Weaver), equitability and standing crop (numbers/ft^2) in the Main and East Forks of Horse Creek, July and September 1979

Watershed	Number of Species		Species Diversity		Equitability		Standing Crop	
	July	Sept.	July	Sept.	July	Sept.	July	Sept.
18	29	27	3.37	3.81	0.51	0.75	67.0	58.3
16	26	26	3.36	3.54	0.57	0.64	68.0	47.3
14	26	34	3.94	4.33	0.86	0.87	64.0	75.0
12	19	28	3.33	3.83	0.76	0.74	50.3	80.3
10	23	26	3.72	3.19	0.83	0.50	45.0	87.7
9	25	26	3.78	3.31	0.84	0.54	43.3	43.0
8	29	25	3.62	3.64	0.61	0.72	83.0	44.0
6	26	29	3.52	3.09	0.64	0.41	43.3	68.0
4	30	30	3.70	3.13	0.63	0.41	59.3	82.3
2	20	21	3.30	2.42	0.70	0.35	36.3	63.0
Main above	21	25	3.29	2.90	0.67	0.42	49.7	80.0
Main mouth	30	27	3.46	3.19	0.53	0.48	52.0	69.3
East mouth	26	30	3.25	2.78	0.52	0.32	59.3	138.0
East above	24	33	3.33	3.16	0.60	0.38	57.7	12.5

In Upper Horse Creek, diversity and equitability values were relatively similar from July to September 1978. In 1979, there was a small increase in diversity and equitability values from spring to fall while densities were similar.

The decline in diversity and equitability values are due to increases in the number of Heterlimnius corpulentis Le Conte and population reductions of the order Ephemeroptera. Bjornn et al.(1977) found that two elmid larvae, Heterlimnius corpulentis and Optioservus sp., clearly favored sediment riffles. They observed up to five-fold density increases in sedimented versus cleaned riffles.

Elmid densities increased in the lower Main from an average of 8.9 per square foot in July 1978 to 16.8 per square foot in July 1979. September samples showed similar increases, from 22.1 per square foot in 1978 to 31.8 per square foot in 1979. Comparisons on the upper Main also indicate large increases of elmid densities in 1979. These increases concur with the sediment analysis reported earlier.

In Figures 7 and 8, the influence of the elmids on diversity is shown for 1979 data. Diversity values at a site are plotted against the site's value when Heterlimnius corpulentis is deleted from calculations. Differences of up to 38 percent (2 Main during September) are found and they generally progress downstream. The exceptions occur above the sediment dams on the Main and East Forks. Low densities of elmids result in increased diversities from watershed 14 upstream.

The elmid beetle influences diversities most in September due to its higher numbers. Possibly this is related to sediment being scoured from riffles during high water. Bjornn et al. (1977) also noticed increased elmid densities between control and manually cleaned riffles through the summer. Part of the changes may be a result of seasonal population variations, but the beetle Heterlimnius corpulentis has a two-year life cycle (Leech and Chandler 1968) which would tend to minimize these variations. It seems possible that sediment deposition is the factor causing increases in the beetle numbers and decreases in insect diversity indices.

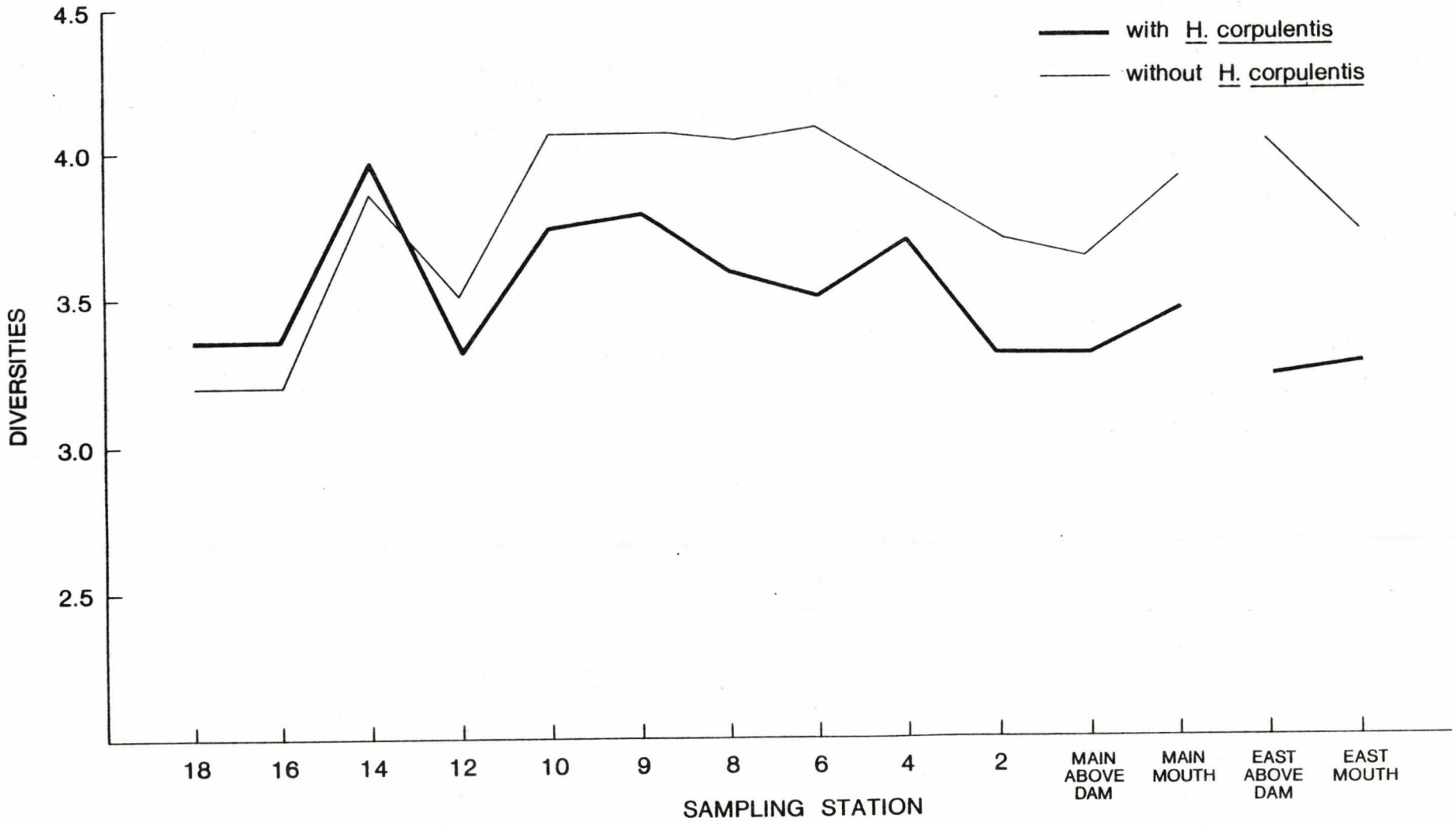

Figure 7. Influence of Heterlimnius corpulentis Le Conte on insect diversity (Shannon-Weaver) in the Main and East Forks of Horse Creek, July, 1979.

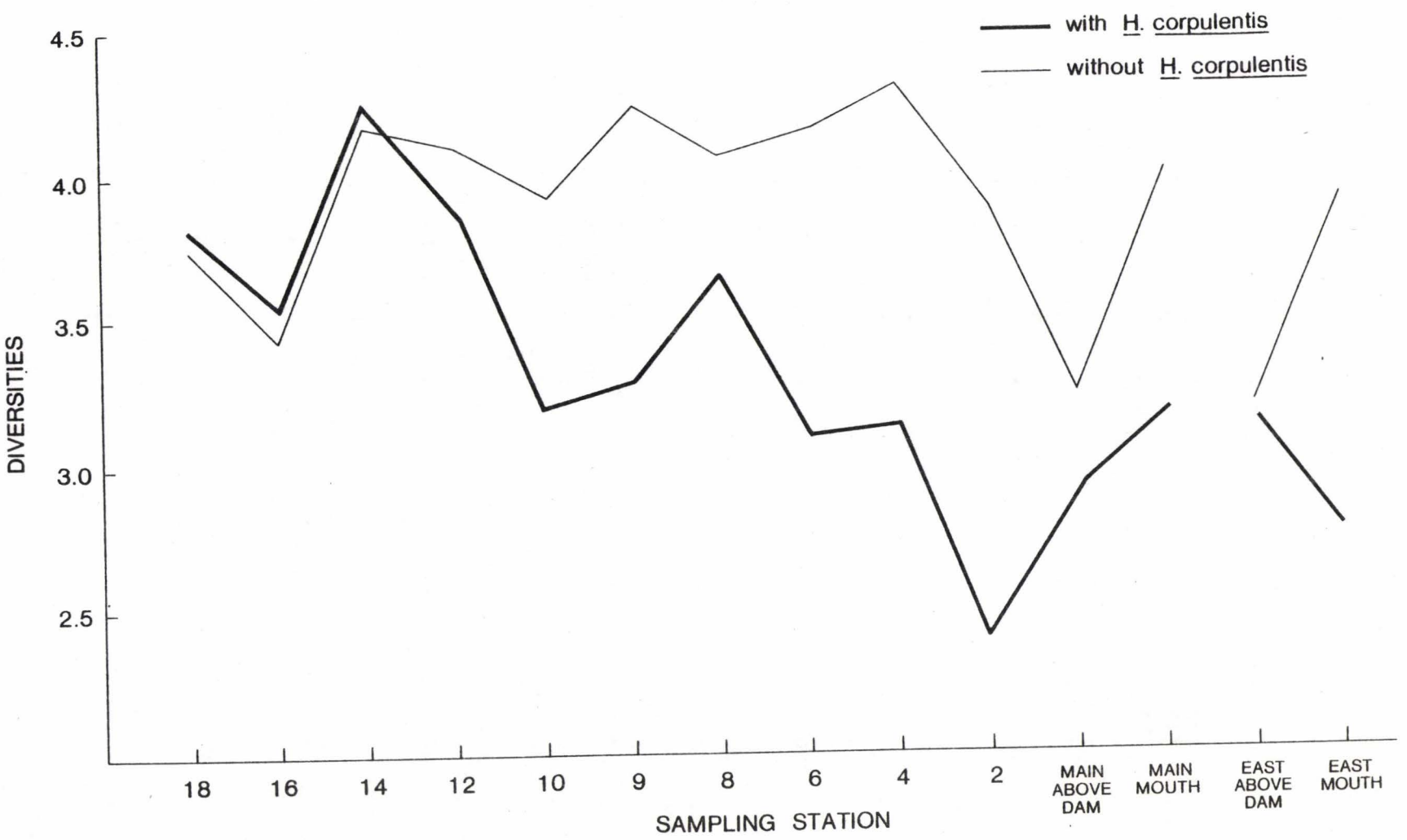

Figure 8. Influence of Heterlimnius corpulentis Le Conte on insect diversity (Shannon-Weaver) in the Main and East Forks of Horse Creek, September, 1979.

Part II

Sediment Storage and Aquatic Insects in the North Side Watersheds

The ongoing studies in the Horse Creek Experimental Watersheds are quantifying sediment entering streams from roads and leaving the watersheds at their mouths. In this phase of the study we are concerned with the quantities of sediment deposited between the road-stream crossings and the watershed mouths. We are attempting to answer these questions: How far does road sediment travel in streams before it is deposited? Are increased or decreased peak flows (due to roads) scouring or depositing sediment? If sediment accumulates in the streams below roads, how long does it stay? What changes take place in stream substrate sizes below roads?

Stream Aggradation-Degradation Measurements

We chose watersheds 6, 8, 10, 12, 14 and 16 to measure sediment storage and insect populations in streams. These watersheds have first and second order streams which are less than one mile in length. Watershed 16 was crossed with a standard I road, and watershed 8 was crossed with a standard II road in 1978. Watersheds 14 (standard II), 12 (standard I unstabilized), and 10 (standard II unstabilized) were not roaded until 1979. Watershed 6 is a control watershed that will not be roaded.

We developed a method to measure sediment storage which is similar to the "sag tape" method commonly used to measure deposition in sediment dams. Transects were 20-40 feet long. Logs were placed across the stream at the upper and lower (upstream and downstream) ends of the transects (Figures 9 and 10). Two tapes were stretched from the upper to the lower log parallel to the stream; one on each side of the stream. These were held by permanent nails in the logs. A movable cross tape could then be placed from side tape to side tape. These longitudinal and cross tapes with permanent nails in logs make it possible to return to any point within the transect year after year. For example, the cross tape might be placed at 2 feet on the left longitudinal tape and 1 1/2 feet on the right lontitudinal tape. Once these cross tapes are relocated, any point along the cross tape can be located and the level rod placed on the stream bottom at that point. The "height" of that point on the stream bottom can be measured by reading, through a level, the distance from stream bottom to a level place (datum line). The level plane was relocated each time by reference nails in nearby trees.

In each watershed (8, 10, 12, 14 and 16) transect number one was located above the proposed road location on one of the major streams. These are essentially control transects since the road has no effect on them. Transects two, three, and four were located in the high impact area below the road. Transects five and six were placed in the lower reaches nearer the mouths. Transect one represents an upstream-reach control, and transect two is a lower stream-reach control in watershed 6 (Figure 11).

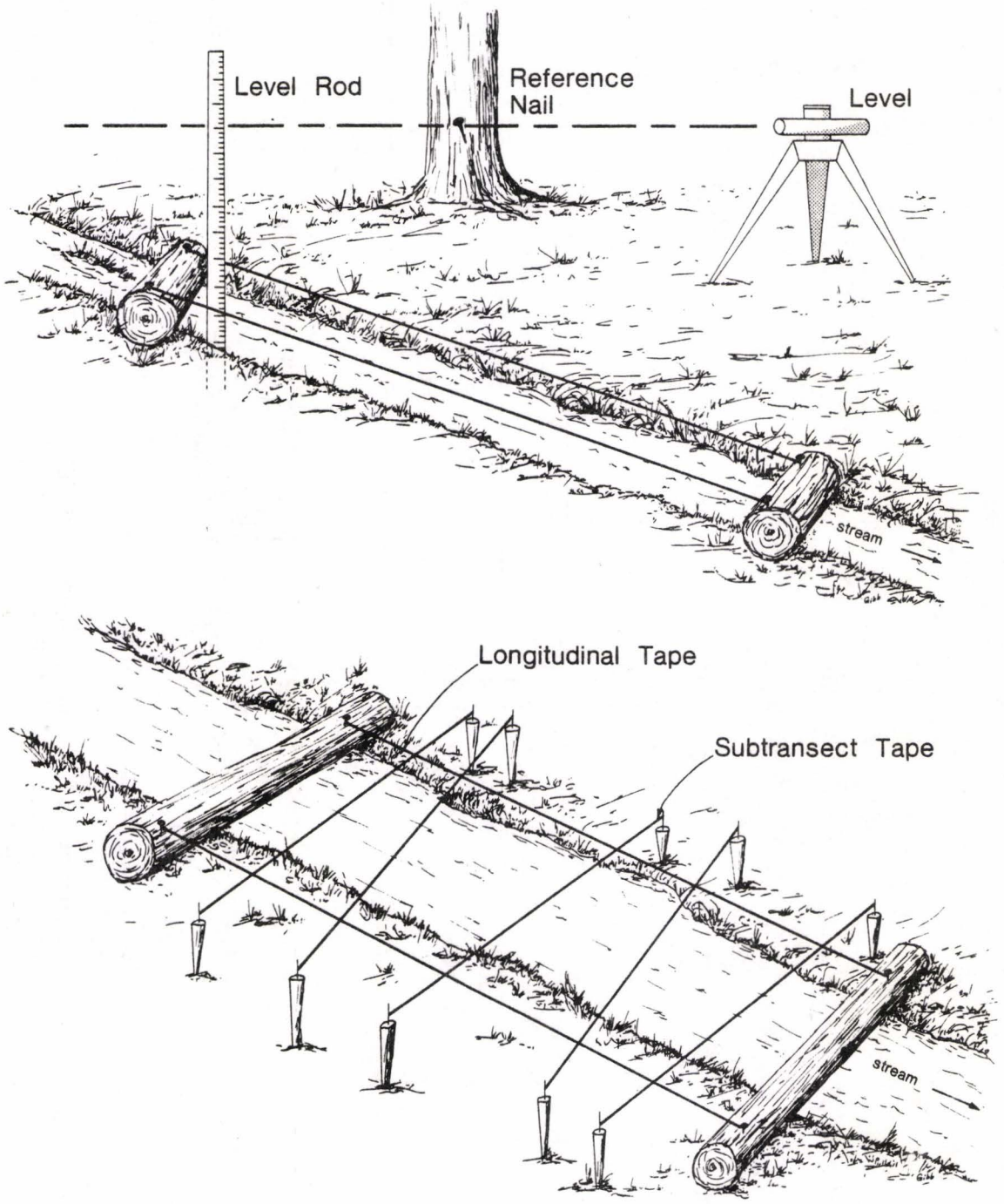

Figure 9. Schematic of a sediment storage transect showing the point relocation method and depth measurements.

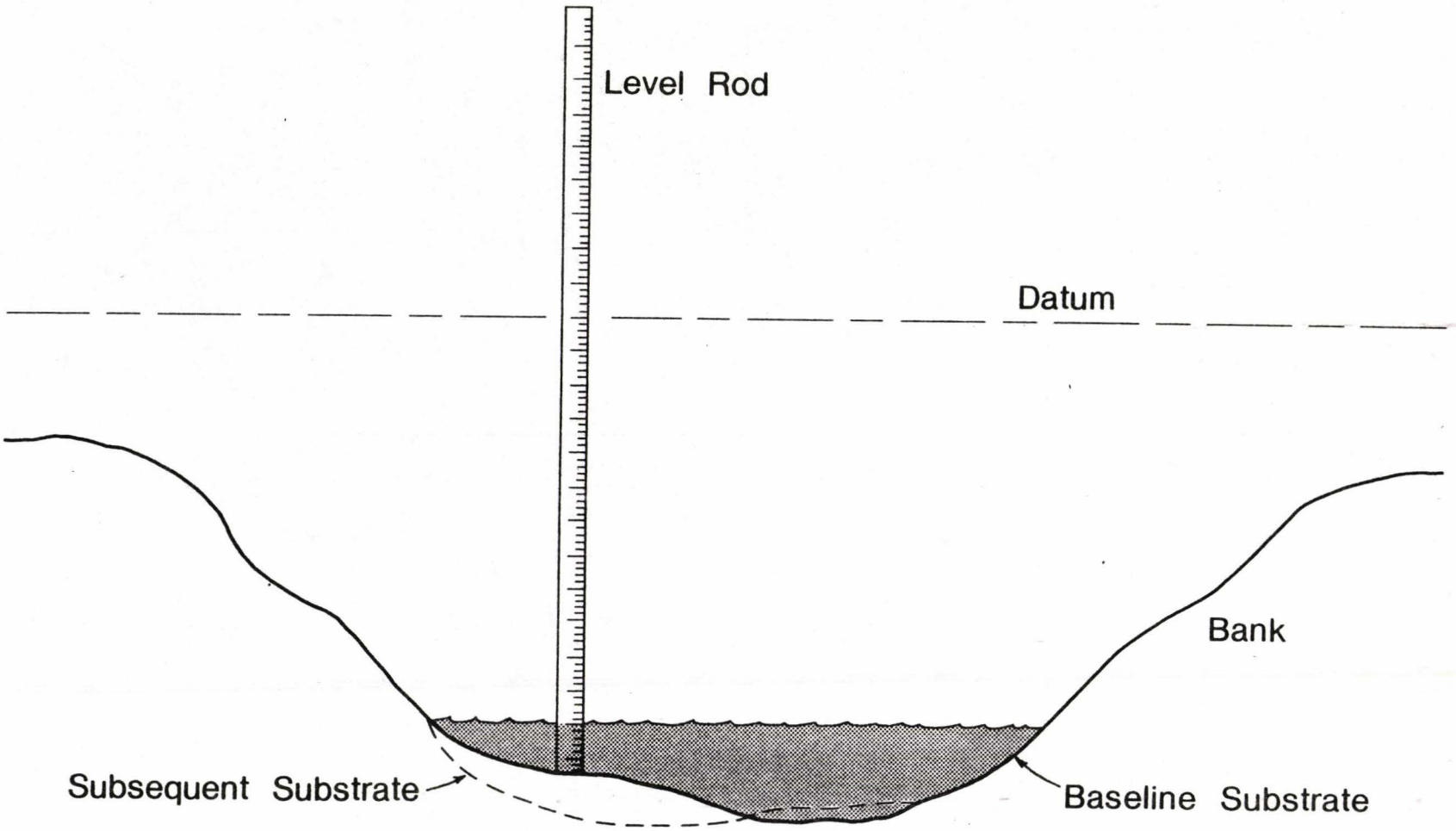

Figure 10. A hypothetical transect showing datum line from which baseline and subsequent levels are measured using a level rod.

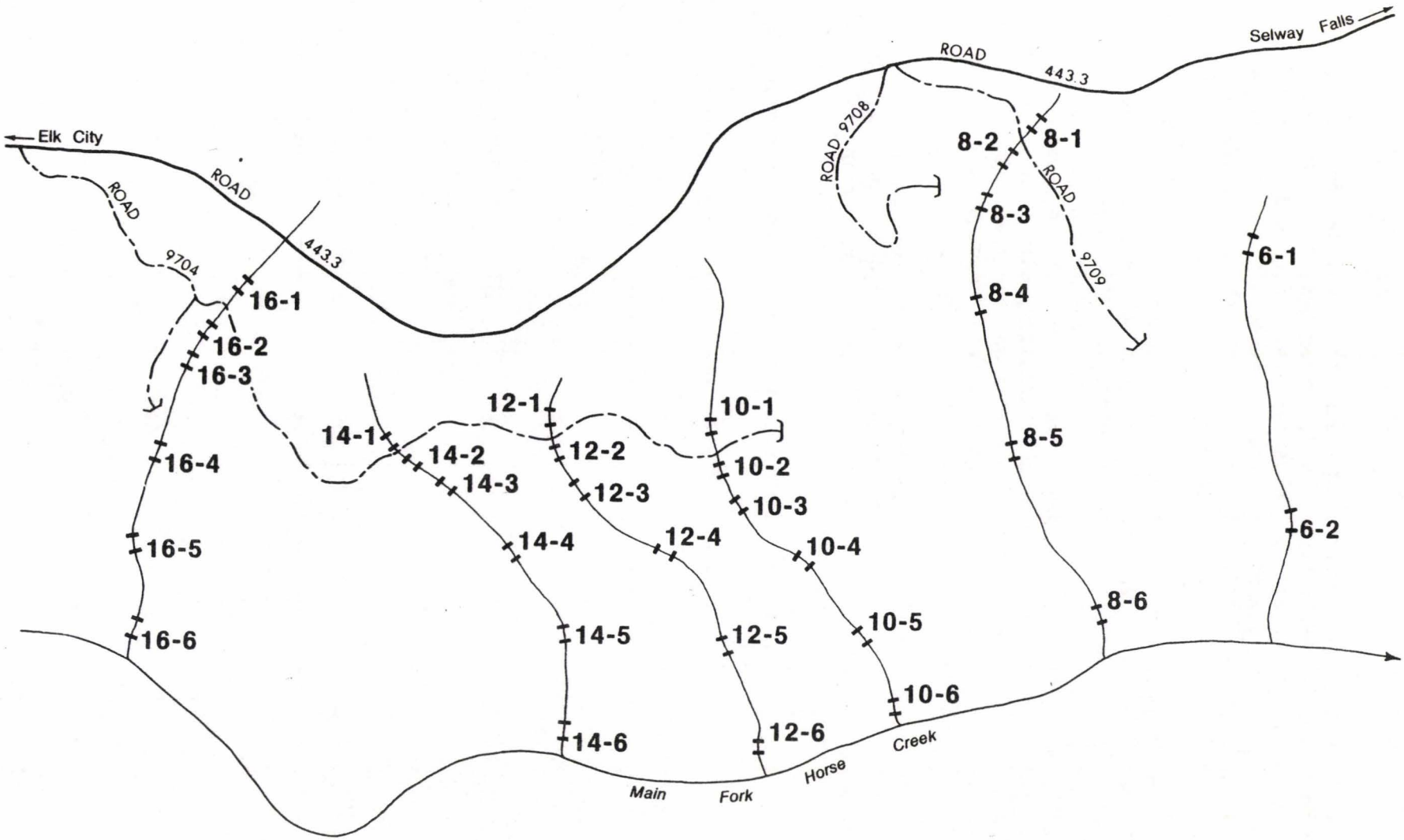

Figure 11. Stream transect and aquatic insect sample locations in north side tributaries of Horse Creek.

Sediment storage was measured in transects of watersheds 6, 8, 14 and 16 during June and September of 1978. Watersheds 8 and 16 were roaded between the spring and fall measurements. Watershed 14 was not roaded in 1978. Spring and fall storage was measured in watersheds 8, 10, 12, 14 and 16 during 1979. All of these watersheds were roaded by the fall of 1979.

The transect data were used to estimate sediment volume changes and stream substrate size changes. Each point on a subtransect represents an area based on distances to adjacent points and distances to adjacent upstream and downstream subtransects. Sediment volume changes were calculated by multiplying height from stream bottom to the level plane times the area represented by the points. Actually, this is a measure of the volume of space between the stream bottom and the level plane. It represents an actual substrate volume change from season to season when one set of data is subtracted from the next.

As height measurements were made for each point in the transect, the substrate size represented by the point was recorded (Table 9). The percent of stream covered by each substrate type and changes in these percents between measurements were calculated.

Table 9.--Stream substrate size classification used in Horse Creek sediment storage transects, 1978

Description	Size
Fines	< 1/8"
Gravel	1/8-1/2"
Cobble	1/2-3"
Rock	> 3"
Bedrock	--
Debris	Organic matter, logs, etc.

Transects covered an average area of 112 ft^2 of stream bottom and consisted of 106 point measurements. Each point represented an average of 1.0 sq. ft. of stream bottom (Table 10).

Table 10.--Channel areas and number of points measured in each stream survey transect

Transect	Channel Area Measured (ft^2)	Number of Depth Points Measured	Average Area Per Point (ft^2)
16-1	92.1	79	1.2
16-2	65.3	74	0.9
16-3	96.8	97	1.0
16-4	160.2	135	1.2
16-5	106.5	99	1.1
16-6	77.2	83	0.9
14-1	72.3	76	0.9
14-2	82.5	90	0.9
14-3	91.3	122	0.7
14-4	156.2	139	1.1
14-5	183.6	136	1.3
14-6	167.7	117	1.4
12-1	89.7	82	1.1
12-2	38.5	53	0.7
12-3	123.3	97	1.3
12-4	107.1	95	1.1
12-5	110.2	95	1.2
12-6	157.5	133	1.2
10-1	74.8	100	0.7
10-2	69.8	95	0.7
10-3	116.7	117	1.0
10-4	62.1	78	0.8
10-5	100.5	112	0.9
10-6	117.8	105	1.1
8-1	41.7	56	0.7
8-2	113.9	139	0.8
8-3	89.6	121	0.7
8-4	116.5	125	0.9
8-5	175.4	167	1.0
8-6	307.0	143	2.1
6-1	68.4	91	0.7
6-2	158.2	137	1.1
$\overline{X}$	112.2	106	1.0

In 1979 transects 8-2 and 12-6 were measured twice to get an estimate of measurement error. It is important to determine whether aggradation or degradation is actually occurring or whether the observed seasonal differences are small enough to be attributed to chance. Transect 12-6 is representative of upstream transects where streams are narrow and bottom material characteristically has a greater percentage of fines and debris. Transect 8-2 is typical of downstream transects with wider streams, larger bottom material, and less debris. Replicate measurements were made a few hours apart and field personnel operating the level rod and transit exchanged positions to optimize the errors.

The difference in deposition between replicates was 0.24 inch in transect 8-2 and 0.12 inch in transect 12-6. The average difference in deposition was 0.18 inch. Calculation of the standard deviation of the differences allows more meaningful interpretation of seasonal changes in sediment depth. The standard deviation of the differences over both transects is 0.052 (n = 276, range = 0.0-0.42) (Table 11).

Table 11.--Paired t-test results of pre- and post-road construction in watersheds 8, 10, 12 and 16, and sites 2 to 4

	t Value	Degrees of Freedom	Standard Deviation	95% Confidence Intervals
Diversity	-2.802**	11	+ .095	.057-.475
Standing Crop (#'s/ft^2)	-2.056*	11	4.888	.7-20.8

Aggradation-degradation measurements were anlyzed as seasonal changes. A spring measurement alone, for example, is of no value until compared to a fall measurement. Therefore, the four measurements during 1978-79 give changes in stream bottom depths during summer 1978, winter 1978-79, and summer 1979 (Table 12).

Table 12.--Seasonal changes in substrate depth (aggradation-degradation) during road building activity in first and second order Horse Creek streams.

Transect	Stream Aggradation-Degradation (inches) Summer 1978	Winter 1978-79	Summer 1979	Accumulative
6-1	-0.19	+0.23	-0.14	-0.10
6-2	+0.06	+0,06	+0.22	+0.34
8-1	-0.74	+0.31	+0.53	+0.10
8-2	+0.52	+0.20	+0.24	+0.96
8-3	+0.24	-0.86	-0.07	-0.69
8-4	0.00	+0.19	+0.12	+0.31
8-5	+0.24	+1.04	+0.26	+1.54
8-6	+0.13	-0.16	+0.14	+0.11
10-1			0.00	0.00
10-2			+0.53	+0.53
10-3			+0.65	+0.65
10-4			+0.38	+0.38
10-5			+0.23	+0.23
10-6			+0.02	+0.02
12-1			+0.25	+0.25
12-2			+0.25	+0.25
12-3			+0.10	+0.10
12-4			+0.65	+0.65
12-5			+0.29	+0.29
12-6			+0.04	+0.04
14-1	-0.13	--#	+2.44*	+2.31
14-2	+3.91	-2.17	+1.79	+3.53
14-3	+2.39	-1.37	-3.00	-1.98
14-4	+0.46	-0.58	+0.31	+0.19
14-5	-0.11	+0.30	+0.47	+0.66
14-6	-0.07	+0.50	+0.70	+0.50
16-1	+0.35	-o.01	+0.06	+0.40
16-2	+1.01	-0.95	+0.42	+0.48
16-3	-1.31	+0.12	+0.01	-1.18
16-4	+0.17	-0.14	-0.04	-0.01
16-5	+0.16	+0.26	-0.06	+0.36
16-6	+0.20	+0.23	+0.40	+0.83

Benchmark trees destroyed during winter.
* Decomposed stump fell into transect (debris increased from 31.8% to 62.8%).

If we examine a composite of seasonal aggradation-degradation changes over all watersheds for the same transect locations (transects 1 above road, transects 2 below roads, etc.), we can see where and when deposition and scouring occur. Table 13 is a composite of roaded watersheds only and shows seasonal changes during the first summer of roading, first winter after roading, and second summer after roading. Transects 1 which are above the road reflect natural changes plus measurement error. Transects 2 which are immediately below the roads received 0.82 inch of sediment build-up during the first summer of roading. The first winter after road building transects in this location lost 0.37 inch, undoubtedly during spring runoff. During the second summer after road building transects 2 built up 0.33 inch of sediment.

The stream reaches at 100-150 yards below the roads (represented by transects 3) degraded -0.66 inch the first summer, -0.37 inch during the first spring runoff, and -0.03 inch the second summer.

Transects 4, 5, and 6 increased in substrate depths during all three periods after road building. Averaging changes in transects 2 through 6 (all below the roads) indicates that sediment contributions to the full lengths of the watersheds are +0.12 inch the first summer and +0.12 inch the second summer. Transects near the roads received less sediment the second summer, but those farther down the watersheds received more.

Watersheds 8 and 16 were roaded during 1978. Watersheds 10, 12, and 14 were roaded during 1979. The magnitudes of sediment deposition during the first summer of roading are similar for these two groups of watersheds (Figure 12). Figure 12 indicates that the upper reaches of watersheds 10, 12, and 14 will scour during the winter of 1979-80 and the lower reaches will receive deposition through the winter (1979-80) and summer of 1980.

Table 13.--Composite of aggradation-degradation changes over all watersheds during their first and second summers after road building.

Transect	Change During First Summer Roaded (Watersheds 8, 10 12, 14, 16)	Change During First Winter Roaded (Watersheds 8, 16)	Change During Second Summer roaded (Watersheds 8, 16)	Accumulative Change of 2 years (Watersheds 8, 10, 12, 14 16)
1	-0.07	+0.18	+0.15	+0.61
2	+0.82	-0.37	+0.33	+1.15
3	-0.66	-0.37	-0.03	-0.62
4	+0.30	+0.02	+0.04	+0.30
5	+0.28	+0.65	+0.10	+0.62
6	+0.09	+0.03	+0.27	+0.30
Ave. *	+0.12	-0.01	+0.12	+0.35

* Average of transects below the road (transects 2, 3, 4, 5, 6)

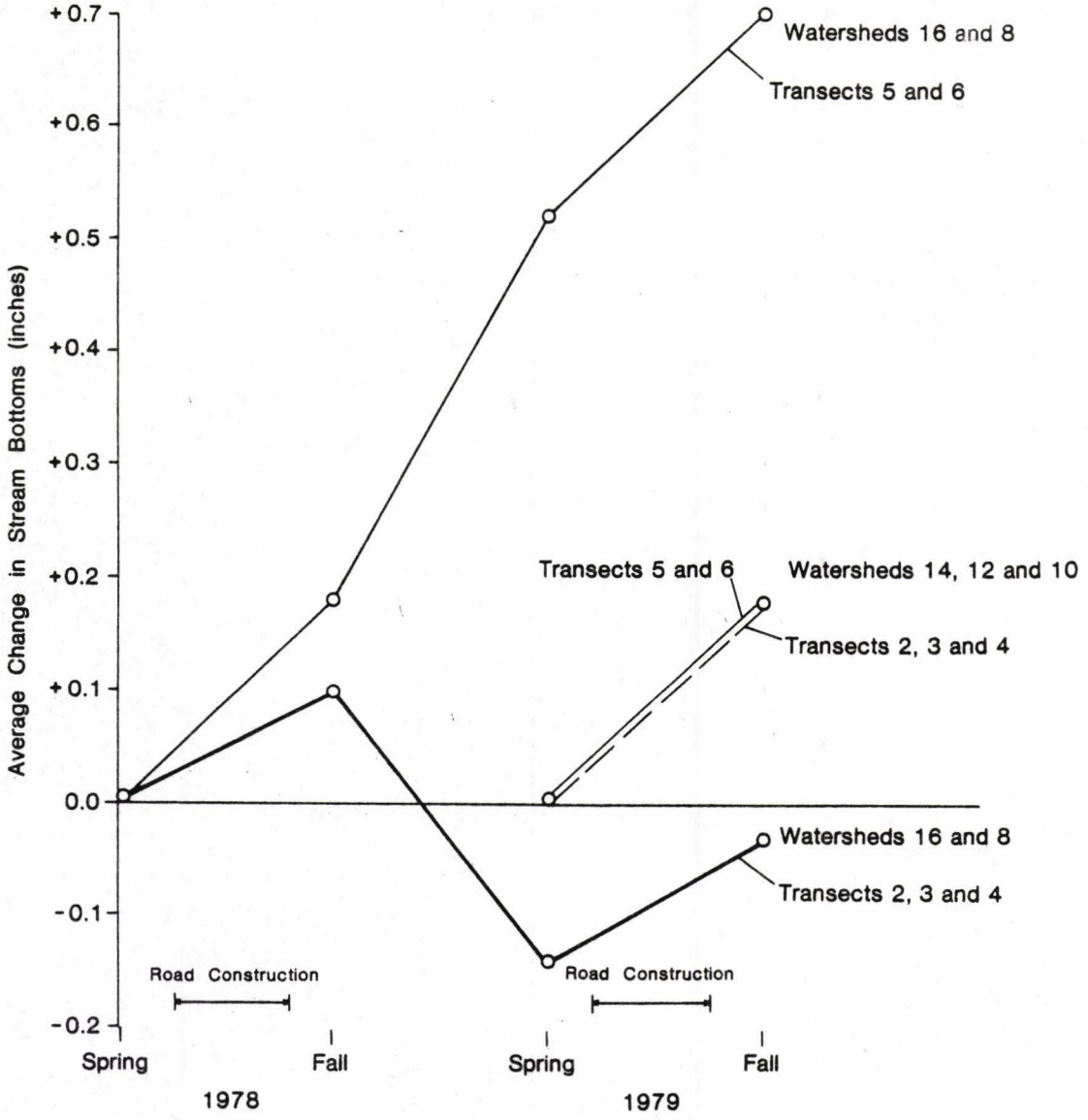

Figure 12. Stream substrate aggradation and degradation during the first and second years of road construction in the Horse Creek drainages.

Besides an increase or decrease in stream substrate depth associated with each point in a transect, there was also a substrate classification recorded for each point. Changes in substrate depth are most often a result of movement of fine material. As might be expected, there is a relationship between changes in depth of substrate and the percent fines making up the substrate.

Percent fines averaged over all transects below the roads increased by 5-10 percent during the first summer of road building (Table 14). Percent fines decreased in these transects during the winter and again increased over the second summer. Substrate aggradation is always associated with an increase in percent fines and, likewise, the converse is true.

Table 14.--Changes in percent fines in first and second order Horse Creek streams during 1978-79 road building activity

Non-Impacted Stream Reaches (Transect 1 above roads)		
Summer 1978 (4)	Winter 1978-79 (4)	Summer 1979 (6)
- 7.4	+ 6.8	+ 4.4

Immediate Impact Stream Reaches (Transects 2, 3 & 4 below roads)			
Summer 1978 (6)	Winter 1978-79 (6)	Summer 1979	
		Roaded in 1978 (6)	Roaded in 1979 (9)
+ 9.6	- 3.2	+ 9.7	+ 14.6

Delayed Impact Stream Reaches (Transects 5 & 6 near mouths)			
Summer 1978 (4)	Winter 1978-79 (4)	Summer 1979	
		Roaded in 1978 (4)	Roaded in 1979 (6)
+ 5.7	0.1	+ 1.8	+ 4.4

( ) Number of transects involved

Within each transect a sample of fines (< 1/8" diameter) was taken to analyze for percent organic material. Aquatic insects are dependent upon allocthonous (in-stream) organic matter for food. Decreases in the organic to inorganic ratio in fines due to road building could be one mechanism which reduces insect numbers. In 1978 organic matter in fines increased an average of 3.0 percent in the upper reaches of drainages which were roaded. Over winter the organics decreased 3.0 percent and again increased the second summer. The lower reaches of these roaded watersheds increased slightly in percent organics over these three seasons (Figure 13). These trends are similar to trends in sediment deposition discussed earlier. It appears that fines building up over the summer months have higher percentages of organics than the fines left after spring runoff.

Aquatic Insects

Aquatic macroinvertebrate samples were collected in the Horse Creek watersheds (6, 8, 10, 12, 14 and 16). The six sites in each watershed were at the same location as the sediment transects. The samples were collected at approximately the same time as the sediment transects.

Laboratory analysis of the samples is described in Part I of this report. Paired t-tests with diversity, standing crop, and equitability were used to evaluate road effects.

Benthic macroinvertebrate collections contained five orders of insects including Trichoptera (Caddisflies), Ephemeroptera (mayflies), Pleocoptera (stoneflies), Diptera (true flies), and Coleoptera (beetles). In addition, Turbellarians (flatworms), Oligochaetes (worms), Gastropods (snails), Bivalves (clams), and the larvae of Ascaphus truei (tailed frog) were represented in the samples.

Caddisflies were the most abundant organisms collected in both 1978 and 1979. Of these, Neothremma sp. was the most abundant genus in four of the tributaries. Densities were generally greatest in the mid reaches of the streams and declined dramatically in the lower sites. The genus Rhyacophilia was also important, generally having at least three species present in each sample.

Other important insects included the stonefly, Peltoperla sp., which had distributional patterns similar to that of Neothremma, members of the Nemoura complex, and Arcynopteryx bradleyi. Dominant mayflies were Cinygmula sp., Ameletus similor and members of the Ephemerella complex. The dipterans Tipula sp. and Palpomyia sp. were also dominant in both years.

Other important organisms were the clam Pisidium sp., Oligochaetes, and the snail Hydrobia sp.

A significant decrease in species diversity and standing crop occurred following road construction when the data from each of the watersheds were combined (Table 15). Equitability values, although not statistically significant, also decreased after construction.

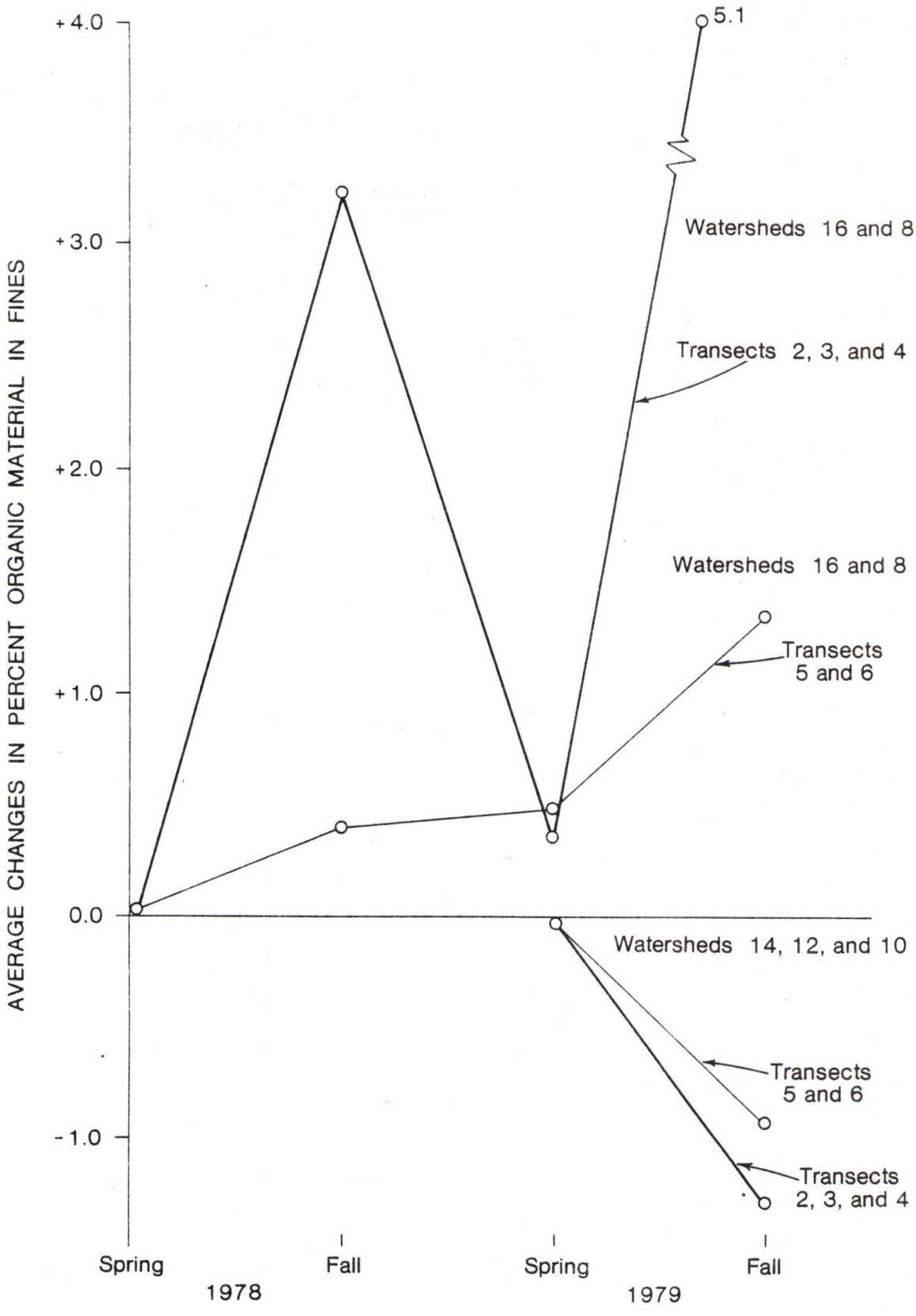

Figure 13. Changes of percent organic materials in fines (< 1/8" diameter) during the first and second years of road construction in the Horse Creek drainages.

Table 15.--Analysis of species diversity, standing crop (numbers per square foot) and number of species in Horse Creek tributaries before and after road construction.

	Pre-Construction (Spring)			Post-Construction (Fall)		
Site	Species Diversity	Standing Crop	Number of Species	Species Diversity	Standing Crop	Number of Species
8-2	3.86	31.3	23	3.23	9.3	11
8-3	3.19	14.0	15	3.09	8.0	11
8-4	3.68	28.0	19	3.04	12.7	14
8-5	3.32	43.3	28	3.19	26.7	18
8-6	2.28	59.0	22	2.91	31.7	18
10-2	3.09	58.0	29	3.54	21.3	18
10-3	3.78	38.7	27	3.24	43.0	22
10-4	4.05	28.3	23	3.90	22.3	21
10-5	3.85	58.3	29	3.89	33.0	25
10-6	4.05	41.7	28	3.53	20.7	20
12-2	3.67	84.3	28	3.81	91.7	30
12-3	3.48	52.7	25	3.73	39.0	22
12-4	4.00	78.7	27	3.63	100.0	25
12-5	3.87	63.7	28	3.68	36.3	20
12-6	3.68	19.0	19	4.15	48.3	27
16-2	3.75	73.3	32	3.14	41.7	21
16-3	3.22	79.3	24	2.84	79.7	30
16-4	3.40	54.7	22	3.60	32.0	20
16-5	3.07	38.7	17	3.39	48.7	22
16-6	2.67	16.7	11	3.17	30.3	17

The area of impact was greatest in sites 2, 3, and 4 which are relatively close to the road. Generally, little effect was observed in sites 5 and 6. These lower sites acted quite independently of any trends occurring near the road (Table 15).

The greatest effects following construction were observed in watershed 8. Population levels decreased by over 50 percent even in the lower sites, and averaged only 10 per square foot in the upper sites. The number of species was the lowest for any watershed examined, and the diversities dropped accordingly. Transect data show that 1.04 inches of sediment were deposited at transect 5 during the first winter which was more than twice as much deposited in any downstream transect during that time.

Watersheds 10 and 16 reacted similarly, showing decreases in diversity values and variable reductions in the population levels. The most dramatic equitability reductions occurred just below the road in watershed 16.

Minimal effects were observed at the individual sites in watershed 12. Data for watershed 14 were not used in this analysis since road construction had started prior to sampling.

Important to note is that the magnitude of the changes was not great enough to seriously hurt the aquatic communities since Horse Creek streams have high populations and good diversities naturally. Diversity indices rarely fell below 3, and equitability values usually indicated moderate degradation of the habitat. It is too early to firmly conclude, but it appears that recovery of the streams based on watersheds 8 and 16 seems complete a year after construction (Figure 14).

Aquatic macroinvertebrates in the Horse Creek tributaries were dominated by detritivores such as stonefly Peltoperla sp. and the mayfly Cinygmula sp. (Gilpen and Brusven 1970, Merritt and Cummins 1978). The periphyton studies support this, with the low levels of production indicating the heterotrophic nature of the watersheds. One apparent exception is the high population levels of Neothremma sp. and Hydrobia sp., both of which are grazers (Merritt and Cummins 1978). One or the other of the organisms dominates a particular watershed, and population oscillations often seem to be compensatory, indicating the competition between the organisms. In watershed 16, during September 1978, Neothremma sp. averaged 21.7 per square foot, while conversely Hydrobia sp. averaged only 0.3 per square foot. In watershed 10, Hydrobia sp. averaged 7.2 per square foot, while Neothremma sp. averaged 1.6 per square foot (Figure 15).

Goeriella buamani Denning, a very rare caddisfly, was found in all watersheds. G. L. Wiggins, who first described the larva in 1974, calls it a "phylogentic relict" (Wiggins 1976). The caddisfly, believed to occur in only spring seepage areas of Idaho and Montana, was collected throughout the upper reaches of the streams.

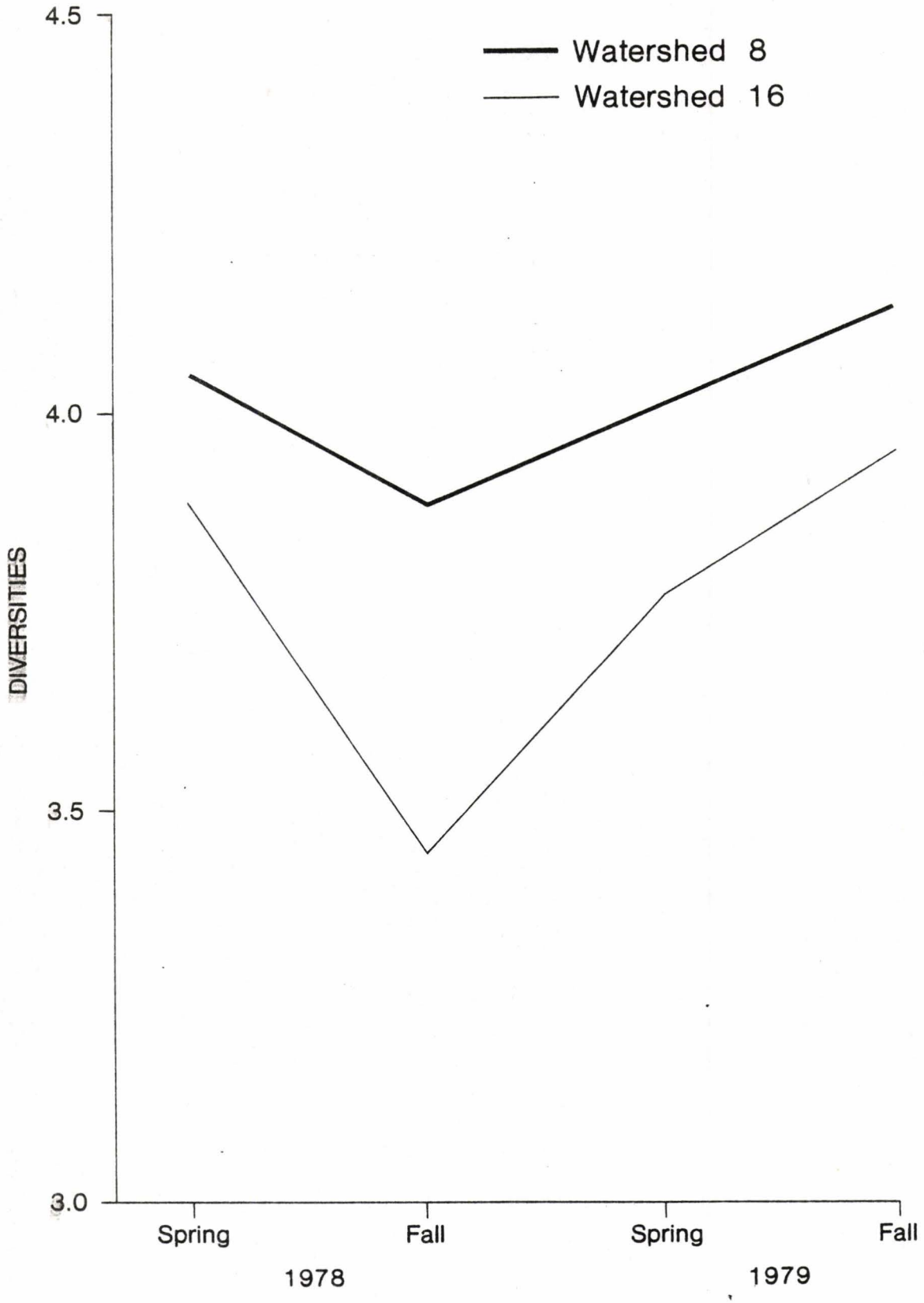

Figure 14. Diversity values of sites 2, 3, and 4 combined, 1978 and 1979, in watersheds 8 and 16 (road construction occurred during the summer, 1978).

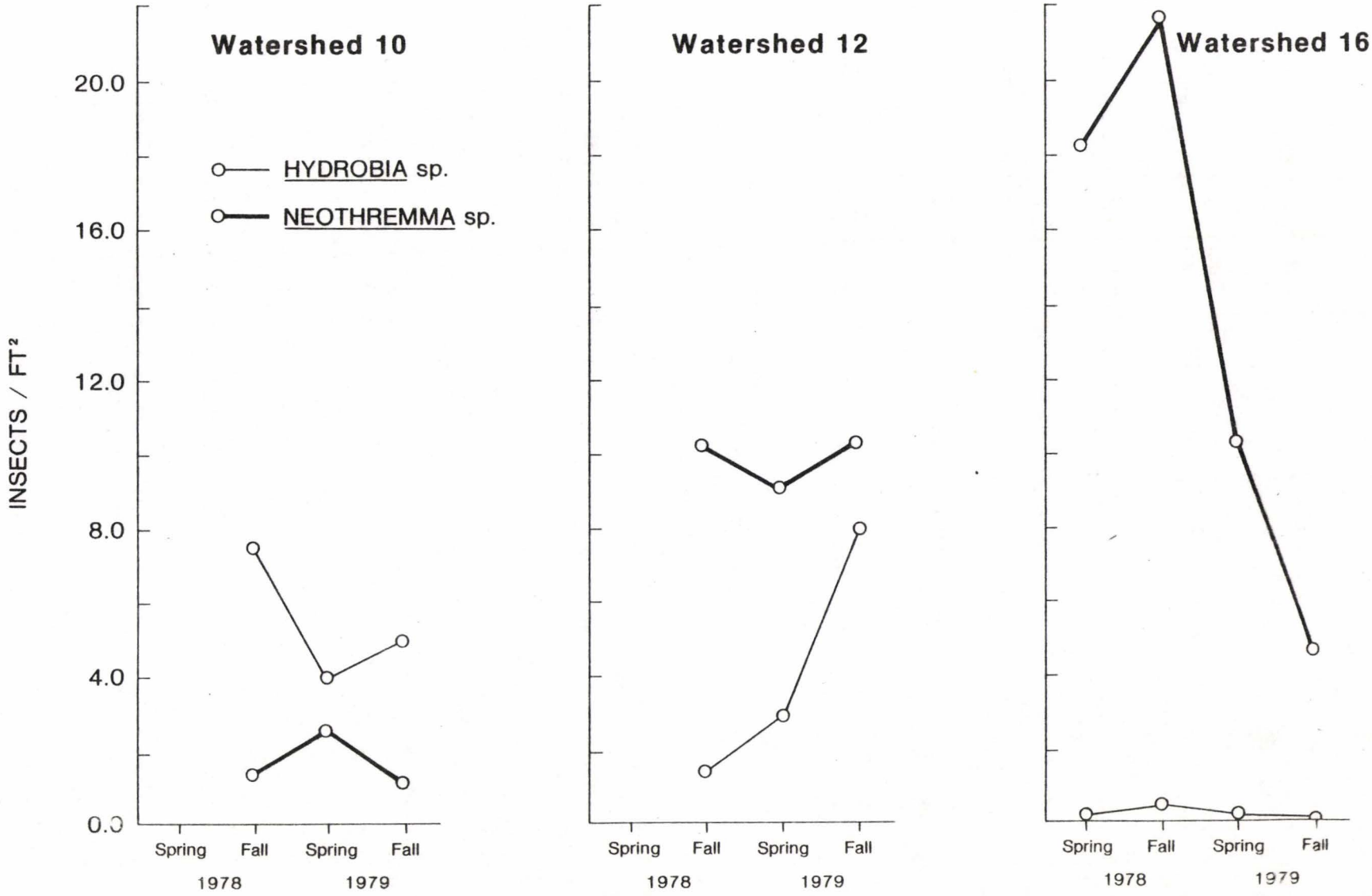

Figure 15. Population change comparisons between two grazers, Hydrobia sp. and Neothremma sp., in Horse Creek tributaries during 1978 and 1979.

A control site was selected above the road but was not used in the data analysis. The site often represented first order streams, whereas the other sites were usually in second order streams. This habitat difference delineated the aquatic communities. The fauna of the control site had very few stoneflies and mayflies and large numbers of Dipterans, Oligochaetes, and Pisidium sp.

Much of the impact of road construction may have been masked by natural population fluctuations in running waters. However, spring populations are usually at a low level (Hynes 1970) resulting in part from the scouring and impaction of high runoff. We observed increased population levels in the unroaded watershed 14 from spring to fall 1978. This was also found in similar communities of the Silver Creek, Idaho, tributaries in 1973 and 1974 (Brusven and Hart 1975). Our comparisons of pre-road populations with post-road populations are also a comparison of spring and fall populations. Since we can be reasonably sure that fall populations naturally would be greater and more diverse, we attributed lower fall populations to road sediment. It would have been valuable to calibrate pre-road insect populations over several seasons before road construction.

In watershed 12, where the least impact on insects was seen, construction was completed in late July and allowed sufficient time for recolonization of the stream before fall sampling. Recolonization requires about six weeks, with the dominant source of the fauna coming from downstream migration (Williams and Hynes 1976). The degree of population reduction from spring to fall in Horse Creek drainages seems to be related to the completion date of construction. The greatest reduction in numbers was seen where construction was not complete until early September, immediately prior to fall sample collection.

The second year's data for watersheds 8 and 16 may be demonstrating the resiliency of the streams. Fall insect populations are high within one year following construction. This is especially noticeable in watershed 8 where construction was not able to be completed before winter. The road was left in subgrade condition although the permanent culverts had been placed. Spring 1979 samples were taken while the road was in the over-winter condition (closure with a heavy straw mulch to retard erosion) and showed little deleterious effects from over-wintering.

Part I: Summary and Conclusions

- Hatchery stock rainbow trout (Salmo gardneri) were the only fish species found in Horse Creek.

- Number of fish collected by electrofishing averaged 61 fish/1000 yards of stream in 1978 and 134 fish/1000 yards in 1979.

- Horse Creek trout averaged 10.2 cm in lenth during 1978 and 12.1 cm during 1979 and ranged from 5.5 to 26.5 cm.

- Sediment flushed from the Main and East Fork sediment dams is not all removed from the areas immediately below the dams during spring high flow.

- The quantity of sediment stored in the Main Horse Creek varies greatly from summer to summer.

- No relationship was observed between percent fines in stream substrate and numbers of fish collected in Horse Creek.

- Flushing of sediment from the Main and East Fork dams does not cause fish to move out of stream reaches below these dams after flushing.

- Four-year-old (and older) fish in Horse Creek were not larger than 9 inches indicating relatively slow growing conditions for rainbow trout.

- 120-125 adult tailed frogs (Ascaphus truei)/1000 yards of stream were collected during 1978 and 1979 in the Main Horse Creek.

- Tailed frog larvae inhabit only second order streams or larger, but adults range throughout the Horse Creek watersheds.

- Periphyton production is relatively low throughout the drainage, ranging from 1200 to 3147 mg dry-wt/m^2 during the two years.

- The annual flushing of the Main and East Fork sediment dams appears to lower fall insect diversities downstream.

- Increases in Heterlimnius corpulentis, an insect species which favors sedimented riffles, resulted in decreases of fall species diversities during 1978 and 1979 in the upper reaches of Horse Creek.

Part II: Summary and Conclusions

- The stream aggradation-degradation measurement methods used in this study have an average error of 0.18 inch and a standard deviation of 0.052.

- Stream reaches immediately below roads (within 50 yards) received 0.82 inch of sediment aggradation during the first summer of road building.

- These same reaches lost 0.37 inch during the first spring runoff and then aggraded 0.33 inch during the second summer.

- The stream reaches at 100-150 yards below the roads (represented by transect 3) degraded -0.66 inch the first summer, -0.37 inch during the first spring runoff, and -0.03 inch the second summer.

- The downstream reaches (lower half-mile) aggraded during all three periods after road building.

- During the second summer after road building, upstream aggradation decreases and downstream aggradation increases in streams approximately one mile in length.

- Percent fines, averaged over all transects below roads, increased by 5-10 percent during the first summer of road building.

- Fines deposited during the summer months have slightly higher concentrations (approximately 3%) of organic material than fines left after spring runoff.

- There was a statistically significant decrease in macroinvertebrate numbers and diversities in roaded watersheds during the first summer following road construction.

- Transect areas 2, 3 and 4 within 300 yards of the roads exhibited the greatest decreases in insect standing crop and diversities during the first year of roading.

- Watershed 8, which had the highest rate of sediment deposition in its lower reaches, lost 50 percent of its insect standing crop and had the lowest diversities and fewest species in any watershed after the first summer of roading.

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SECTION 11

HYDROLOGIC AND SEDIMENTATION EFFECTS OF FOREST ROAD CONSTRUCTION

LEVEL I

OBJECTIVE

Determine gross hydrologic and sedimentation effects of roads and road standards at the mouths of calibrated watersheds.

A. Determine effects on streamflow rate during construction and thereafter; and determine effects on total water yield over various periods of time after construction.

To meet this objective we need continuous records of stream stage (discharge) and discharge prediction equations between a control subdrainage and the subdrainage to be roaded. Since 1974 or 1975 continuous stage records have been collected on all ten northslope subdrainages. Strip charts from the records have been digitized in a timely manner and hourly stage data has been stored in computer files. These files are then run through a program (DRIPS) to generate a file of average daily discharge for each subdrainage. These files have been generated for water years 1974 through 1979.

Calibration or prediction equations have not been developed for these subdrainages. For calibration purposes, the DRIPS program is not adequate. A new program is needed to generate data in a format compatible with standard calibration techniques. The task of writing a new program is the responsibility of INT-Moscow and was originally scheduled to be completed in FY 80. However, mid year changes in the duties of the computer specialist have delayed this task until the winter of FY 81.

Part of the calibration will be based on changes in flow duration characteristics of the streams. Cooperators with the Idaho Water Resources Research Institute have developed a flow duration generating program and are presently using records from the East and Main Fork Stations to generate flow duration curves. A $6080 cooperative research agreement with the University of Idaho will continue this work on the 10 north subdrainages in Horse Creek.

B. Determine effects on sediment production at the mouths of the subdrainages during construction and throughout the years after construction until harvesting begins.

Bedload catch basins at the mouths of the subdrainages provide a volumetric measure of bedload sediment production on an annual basis. These were installed and have been annually surveyed since 1974 or 1975. Post road construction volumes for subdrainages 18, 16, and 8, one year following construction, do not show an increase due to road construction.

Bulk density measurements were made in four basins in 1975 and 1976 (subdrainages 4, 6, 8 and 16) and seven basins in 1978 and 1979 (subdrainages 6, 8, 10, 12, 14, 16, and 18). This allows conversion of volumetric measurements to a weight basis.

Since the majority of suspended sediment is not deposited in the basins, automatic samplers were installed to periodically sample for suspended sediment concentration. Samplers were installed in February, 1978 (subdrainages 18, 16, 8, and 6) and March, 1979 (subdrainages 14, 12, and 10). Originally, sampling frequency was twice a day during March through October and three times every 48 hours during the winter months. In the summer of 1979 instrumentation was added to enable stage regulated sampling. Our present sampling frequency is twice a day during the snowmelt hydrograph and stage controlled sampling during the remainder of the year.

Samples are transported to the University of Idaho for determination of suspended sediment concentrations. University personnel also maintain the data files for sediment concentrations at the mouths of the subdrainages.

Actual amounts of sediment carried out of the subdrainages in suspension requires consideration of the discharge during the time the sample was taken. This cannot be done until "DRIPS" is modified from its present form.

The only suspended sediment data collected at the subdrainage mouths that has been converted to an actual amount is for the snowmelt period of 1979 for subdrainage 16, selected rain events at various subdrainage mouths, and pioneering and culvert installation activities at all subdrainage mouths.

C. Determine effects of roads on stream channel sediment storage and channel condition.

The original methods called for use of stereo-photography to measure channel storage and condition. This was not done. Instead a cooperative research agreement was entered into with the University of Idaho to determine storage and condition using surveying techniques. In 1978, permanent grid transects were located in the stream courses in subdrainages 16, 14, 12, 10, and 8. Each transect is approximately 30 feet long and five transects are located below the road in each of the subdrainages. The five transects are located between the road crossing and the subdrainage mouth. A control transect is located above the road in all surveyed channels. The grid surveys of channel bottom elevation and particle size are made each July and September. Sediment storage data for 1978 and 1979 has been computerized. The data for those years has also been analyzed and a progress report has been written by the University of Idaho personnel.

Due to the low density of transects per total length of stream and the great variability in stream conditions, calculations of total channel storage is not possible. Based on what is measured in the five transects, only inferences can be made concerning storage for the whole length of stream channel.

There were also two transects located in control subdrainage 6 and a single transect above the roads in subdrainages 16, 14, 12, 10, and 8. Originally these were to be used as control transects. However, those transects located above the roads are generally not representative of the five located further downstream. Those above the road are often in "seep" areas with atypical channels. To improve controls on this portion of the study, three additional transects were located in subdrainage 6 in July, 1980.

Channel grid transects are not located in either the East or Main Forks. However, permanent plots have been located to quantify bottom material size composition on an annual basis. Plots are located above and below the confluence of each north slope gaged stream with the Main Fork and above and below the sediment catch basins on the East and Main Fork. In 1980 additional plots were located along the East Fork to improve control of the study and several plots were deleted along the Main Fork.

LEVEL II

OBJECTIVE

Determine the hydrologic and sedimentation effects in live stream channels at points between the roads and primary streams, defining effects on live water channels and partially defining origin, enroute deposition, and movement of sediment.

A. Determine the contributions of water and sediment to live water channels from identified sections of road.

At each live water crossing in the roaded subdrainages stream discharge and sediment concentrations were monitored at locations immediately above the culvert inlet (Station A), immediately below the culvert outlet (Station B), and at some distance downstream (Station C). In four of the subdrainages, each representing a unique road standard and surfacing treatment combination, these three stations are automated at one stream crossing. Instrumentation consists of H-flumes, stage recorders, and a water sampler. The remainder of the stream crossing stations have small wooden flumes to concentrate and elevate flow. These are referred to as the manual stations. At the manual stations, discharge is measured and a water sample is collected twice a week during the snowmelt hydrograph, and monthly during low flows. During construction activities and rain events the manual stations are monitored more intensively.

We now have manual data for all crossings since the spring of 1977. Quantities of water and sediment moving past each station have been determined for construction activities and selected rain events. Relationships between sediment concentration and stream discharge have been determined for each station. Regressions have also been developed to predict stream discharge and sediment concentration at any C station had the road not been constructed. Quantities of water and sediment moving past the various stations have not been calculated on a seasonal or annual basis. This task is contingent on data generated from the automated stations. Sediment concentration data from the automated stations is current and files are maintained by the University of Idaho as part of a cooperative research agreement. Discharge data from the stage recorders has been collected but the strip charts have not been digitized. We have just received intelligent graphics display system and digitizer to facilitate data analysis. Also, a contract was awarded to Mark F. Pexton to adapt and/or develop programs for our system. These programs are designed specifically to expedite strip chart digitizing and analysis of the data and will provide hard copies of hydrographs and sediment graphs. This objective will be met in FY 81. When completed, this software package should expedite the digitizing of field data forms and the synthesis of a continuous sedimentgraph.

B. Determine changes in stream channel storage and condition between road crossings and the C stations after roads are constructed.

Originally stereo photo plots were to be used to meet this objective. This was not done. However, two channel transects are located between the B and C stations in four different road standard-surfacing combinations. Data was collected both before and after road construction and is scheduled through 1981.

C. Determine rates of flow and disposition of water and sediment emerging from water control and diversion devices.

This objective is currently not being met. There are no measurements being made of either discharge or sediment at these devices. The only data being collected is the length of flow paths of sediment below each relief culvert. This is done each spring and fall.

LEVEL III

OBJECTIVE

Determine the origin, deposition, and movement of sediment from specific portions of the road prism--cut, ditch, roadbed, and fill--and define relative contribution to total sediment load.

A. Determine proportion of sediment delivered to culverts which are derived from or attributable to the roadbed, cut slopes, and ditch.

Ditch profiling has been done each spring and fall since road construction through the fall of 1980. The elevation of the deepest part of the ditch was measured at 10 ft increments for the entire length of road with ditch. There were no cross sections made of the ditch; therefore, extrapolation to an eroded volume are at best, rough estimates. There has been no review of the data to determine its quality or what information it is providing.

A cooperative research agreement was entered into with the University of Idaho. One of the tasks will be to get this data on a computer file and to quantify changes in elevation over time for selected portions of the ditch system. This will be accomplished in FY 81.

Stereo-photo plots were established at 25 locations on cut slopes on roads 9704 and 9708, constructed in 1978. Stereo-photography was taken by the geometronics group in Missoula, in the fall of 1978, and spring and fall of 1979. An additional 30 plots were installed in the summer of 1980 and photos were taken. Measured quantities of cut erosion from the stereo pairs is not available to date.

Cut slope traps were installed on roads 9704, 9708, 9707 shortly after completion of construction. Each trap is four feet long and is designed to intercept material eroded from the cut slope. They measure erosion from the cut slopes along one percent of the total road length. Eroded volumes are measured after spring snowmelt and following major rainstorms during the summer and fall. The resulting time trends in erosion are expressed as cubic feet eroded per 100 feet of road for each standard. This information was used to predict erosion from the cut slopes that could contribute to each C station.

To date there has been no measurement of road surface erosion. During the summer of 1981, small plots may be installed on various road surfaces. Surface runoff and sediment flux will be measured during selected rain events. The purpose is to provide information to calibrate two erosion-water models for the Horse Creek roads. Although there are no measurements of actual roadbed erosion, it is hoped that these models will enable prediction of this information, at least for the continuously monitored road crossings.

B. Determine quantities of material eroded from fill slopes and downslope disposition.

Four-foot long fill slope troughs were constructed and installed along the top of fill slopes on roads constructed in 1978 and 1979. Sampling was stratified by fill slope height category. Approximately one percent of the fill slope length is sampled. Volumes of eroded material are measured as soon as snow disappears, following major rain events, and in late fall. Data are expressed in cubic feet of erosion per 100 feet of fill slope length by height slope category for selected time periods. This information allows prediction of fill erosion from fills that could contribute material to the C station.

Fill slope traps are also located below selected filter windrowed slopes to quantify material passing through the windrows. Approximately 20 troughs were installed in 1978 and have been measured on the same schedule as described above.

Fill slope and trough data is now in a usable form for erosion prediction and evaluation of filter windrow effectiveness.

Fill slope erosion is also measured by a survey of rills and gullies. Average rill dimensions are used to determine eroded volumes. This survey has been done each spring and fall since road construction. However, in the spring of 1980 only a portion of the road was surveyed due to crew time constraints. Information is stratified by fill slope height class and average erosion rates can be determined for each class. Additionally, transport distances are measured along with fill slope steepness and forest floor gradient.

A cooperative research agreement with the University of Idaho was recently created. One objective of this cooperative study is to develop this data into a useful format for prediction of erosion and another is to examine the relationship between forest floor gradient, gully volume, and fill slope steepness. This will be accomplished in FY 81.

SECTION 12

EVALUATION OF SUBGRADE MOISTURE VARIABILITY AND INFLUENCE ON AGGREGATE BASE AND SURFACING THICKNESS DESIGN

INTERIM REPORT

December 16, 1980

STUDY PLAN NO. 6

HORSE CREEK ADMINISTRATIVE RESEARCH STUDY

EVALUATION OF SUBGRADE MOISTURE VARIABILITY AND INFLUENCE ON AGGREGATE BASE AND SURFACING THICKNESS DESIGN

INTRODUCTION

Study Plan No. 6 was devised to obtain data on seasonal variations in road subgrade moisture and density and their effect on aggregate surfacing thickness design. This data will be used to consider seasonal strength variations of subgrade soils in aggregate thickness design and to improve basic design procedures.

Instrumentation was installed and soil samples taken during the summer of 1978. Monitoring was begun in August, 1978 and has continued since then, except for winter periods. Data is being collected basically in accordance with the Study Plan. Modifications to the Study Plan are discussed below.

DATA COLLECTION

Nuclear Depth Probes. Four-foot aluminum tubes were installed at 18 monitoring stations to represent various road template conditions. Moisture and density readings at depths of 0.5, 1.0, 1.5, 2.0, and 2.5 feet below the top of the subgrade have been taken monthly during the field seasons.

Surface Moisture - Density Measurements. Moisture and density measurements at the top of the subgrade were taken with a standard nuclear gage in 1978. However, there was so much scatter in the data that use of the surface nuclear gage was stopped. The problem was apparently caused by the "trench effect" of using the gage in a hole dug through the aggregate surfacing. In place of the nuclear gage, a Washington Densometer was used once in each of the years 1979 and 1980 to measure in-place density on top of subgrade at each monitoring station.

Gravimetric Moisture. Oven-dry moisture contents of soil samples taken monthly in the vicinity of the nuclear depth probe monitoring stations were determined.

Electric Sensors. Sixty-seven electrical resistivity moisture cells were installed in groups of 2 to 4 cells at 26 locations including the 18 nuclear monitoring stations. Sixty-one of the cells have survived and were functioning well at the end of the 1980 field season. Readings have been taken weekly during the field seasons.

Soil Samples. Soil samples were taken at each of the nuclear monitoring stations in 1978. The following standard engineering soil tests were run on all samples: sieve analysis, liquid limit, plastic limit, moisture-density relationship (AASHTO T 99), specific gravity, R-value, and California Bearing Ratio. In addition, CBR tests were run on selected samples at varying moisture contents to establish the relationship between CBR and percent saturation.

Surfacing Performance. Detailed cross-sections have been taken monthly as well as before and after road grading at each monitoring station. Measurements were started in 1980 of road roughness with a Cox electronic roughness meter, which is mounted in a stationwagon. It was originally intended to start roughness measurements in 1979, but manufacturing problems delayed delivery of the instrument. Stereo photography of the road surfacing was given up because of problems in technique. The rill meter was also given up because it was found to be more time consuming than conventional surveying techniques.

RESULTS

Nuclear Depth Probes. The average moisture and density data for the 18 monitoring stations is shown in Figure 1, 2, and 3 for 1978, 1979, and through August of 1980, respectively. There was considerable scatter in the data between stations for any particular date and there are unexplainable changes in density. However, the overall averages indicate relatively small changes, both with depth and with time.

Surface Moisture-Density and Gravimetric Moisture. The average Washington Densometer and gravimetric data is shown in Figures 1, 2, and 3. The data compares roughly with the nuclear and electrical cell data. The in-place density of the top of the subgrade, as measured by the Washington Densometer is about 107 percent of AASHTO T 99 maximum density.

Electric Sensors. The average electric sensor data is shown in Figures 4, 5, and 6 for 1978, 1979, and through August of 1980, respectively. Percent saturation varies from a high of about 82 immediately after spring breakup to a low of about 55 in late summer or early fall. The data seems to repeat itself annually. There appears to be some threshold magnitude of rain required to affect subgrade soil moisture, and that effect is delayed about 2 weeks after the storm.

Laboratory Soil Tests. The average test results on samples from the 18 monitoring stations are shown below:

Sieve Analysis

Sieve Size	% Passing
No. 4	92
No. 10	85
No. 40	64
No. 200	24

L.L. and PI - Nonplastic

Unified Classification - SM

AASHTO T 99, Method C

Maximum Density = 109.9 pcf
Optimum Moisture = 16.6 %

CBR (Soaked) = 11.3
R-value (200 psi Exudation Pressure) = 60

Specific gravity tests are being rerun because of apparent errors. The relationship between laboratory CBR and percent saturation at varying densities is shown in Figure 7.

Surfacing Performance. Cross-section and roughness meter data have not been analyzed.

CURRENT AND FUTURE WORK

A detailed statistical analysis is being made to determine the significance of existing data and to see if any modifications are necessary in field techniques. Preliminary statistical analysis is also being done to correlate moisture and density data to other variables.

Detailed in-place density and gravimetric moisture content tests in the close proximity of several nuclear and electrical stations are planned in 1981. The purpose of these tests is to determine the accuracy of the instrumentation.

At least one more year of field monitoring is planned. Surfacing performance monitoring will be critical in the 1981 field season because of the anticipated heavy timber haul traffic.

SUMMARY

Work under Study Plan No. 6 is progressing as planned, with some minor modifications in field techniques. Nuclear depth probe data has more scatter than is desirable, but it indicates relatively little variation of moisture and density with time or depth. Electric sensor moisture data shows significant drying of the near-surface, subgrade soil from spring breakup until fall rains. The effect of precipitation on subgrade moisture appears to be subdued by the aggregate surfacing and the effect is delayed. Conclusions have not been reached on the relationship of surfacing performance to other variables.

GRAVIMETRIC AND WASHINGTON DENSOMETER DATA

		9/17/78	10/25/78	11/16/78
		9/19/78	11/2/78	11/21/78
		10.9	16.4	17.6

AVERAGE NUCLEAR DATA

	9/17/78	10/25/78	11/16/78
	9/19/78	11/2/78	11/21/78
0.0'	(00.0 Moisture Content, % / 000.0 Density, pcf)		
0.5'	10.7	11.9	14.0
	117.7	123.3	115.7
1.0'	11.4	14.3	15.6
	120.7	115.1	115.2
1.5'	11.2	15.4	14.6
	120.7	112.7	115.5
2.0'	12.3	14.6	14.0
	118.3	114.7	114.8
2.5'	12.0	14.7	13.6
	119.0	113.8	117.6

Depth, feet

Figure 1. Average nuclear, gravometric and Washington densometer data, 1978.

GRAVIMETRIC AND WASHINGTON DENSOMETER DATA

6/20/79	7/19/79	8/15/79	9/18/79	10/30/79
6/27/79	7/24/79	8/16/79	9/20/79	11/6/79

9/18/79
9/20/79
13.8
117.7

AVERAGE NUCLEAR DATA

Depth, feet	6/20/79	7/19/79	8/15/79	9/18/79	10/30/79	
	6/27/79	7/24/79	8/16/79	9/20/79	11/6/79	
0.0'	(00.0 Moisture Content, % / 000.0 Density, pcf)					
0.5'	13.0	10.6	12.9	11.5	11.6	
	117.7	125.1	120.4	120.9	123.1	
1.0'	14.3	13.9	14.6	12.9	12.7	
	117.1	116.0	114.5	118.4	120.1	
1.5'	14.6	13.9	14.0	13.0	12.4	
	115.6	115.2	113.7	117.4	119.2	
2.0'	14.6	14.1	15.1	13.1	12.7	
	116.3	116.0	112.0	116.7	117.1	
2.5'	13.9	13.6	14.3	12.2	11.0	
	118.7	117.4	114.7	119.9	121.4	

Figure 2. Average nuclear, gravimetric and Washington densometer data, 1979.

GRAVIMETRIC AND WASHINGTON DENSOMETER DATA

4/29/80	5/27/80	7/2/80	8/2/80	8/30/80	
5/9/80	5/28/80	7/4/80	8/3/80	8/31/80	
15.6	15.9				

AVERAGE NUCLEAR DATA

Depth, feet	4/29/80	5/27/80	7/2/80	8/2/80	8/30/80
	5/9/80	5/28/80	7/4/80	8/3/80	8/31/80
0.0'	(00.0 Moisture Content, % / 000.0 Density, pcf)				
0.5'	14.2	13.7	13.9	12.8	13.1
	116.7	119.2	117.4	118.2	122.0
1.0'	14.7	14.5	15.2	14.0	13.1
	116.4	117.1	114.3	118.4	121.1
1.5'	14.0	14.5	14.2	13.9	13.2
	117.7	116.1	117.3	116.5	120.1
2.0'	14.5	14.3	14.2	13.9	13.4
	116.2	117.4	118.0	118.8	118.9
2.5'	14.9	14.5	14.3	13.4	13.0
	117.1	116.1	117.1	120.4	122.5

Figure 3. Average nuclear, gravimetric and Washington densometer data, 1980.

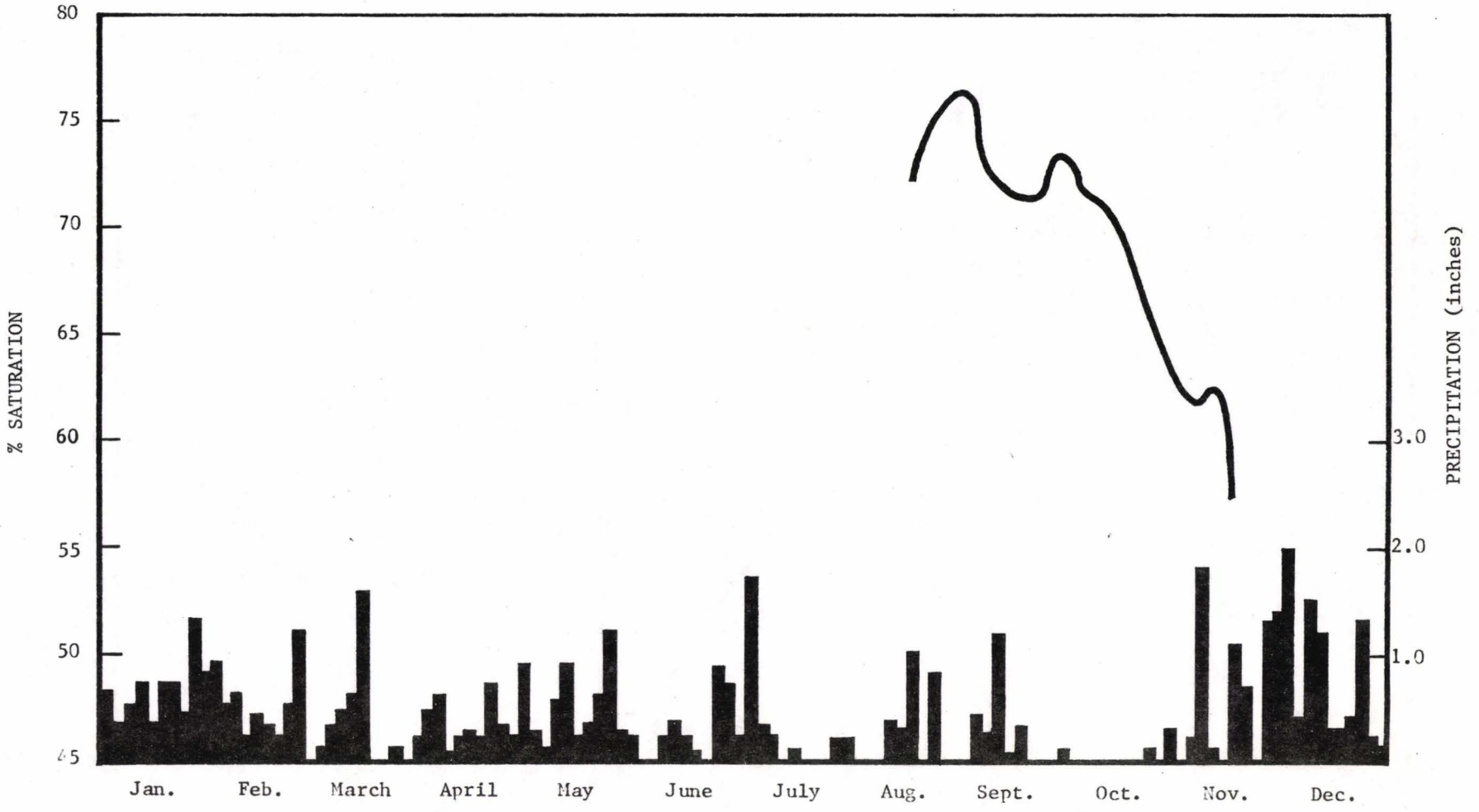

Figure 4. Average percent saturation of subgrade soil and precipitation, Horse Creek road 443.2, 1978.

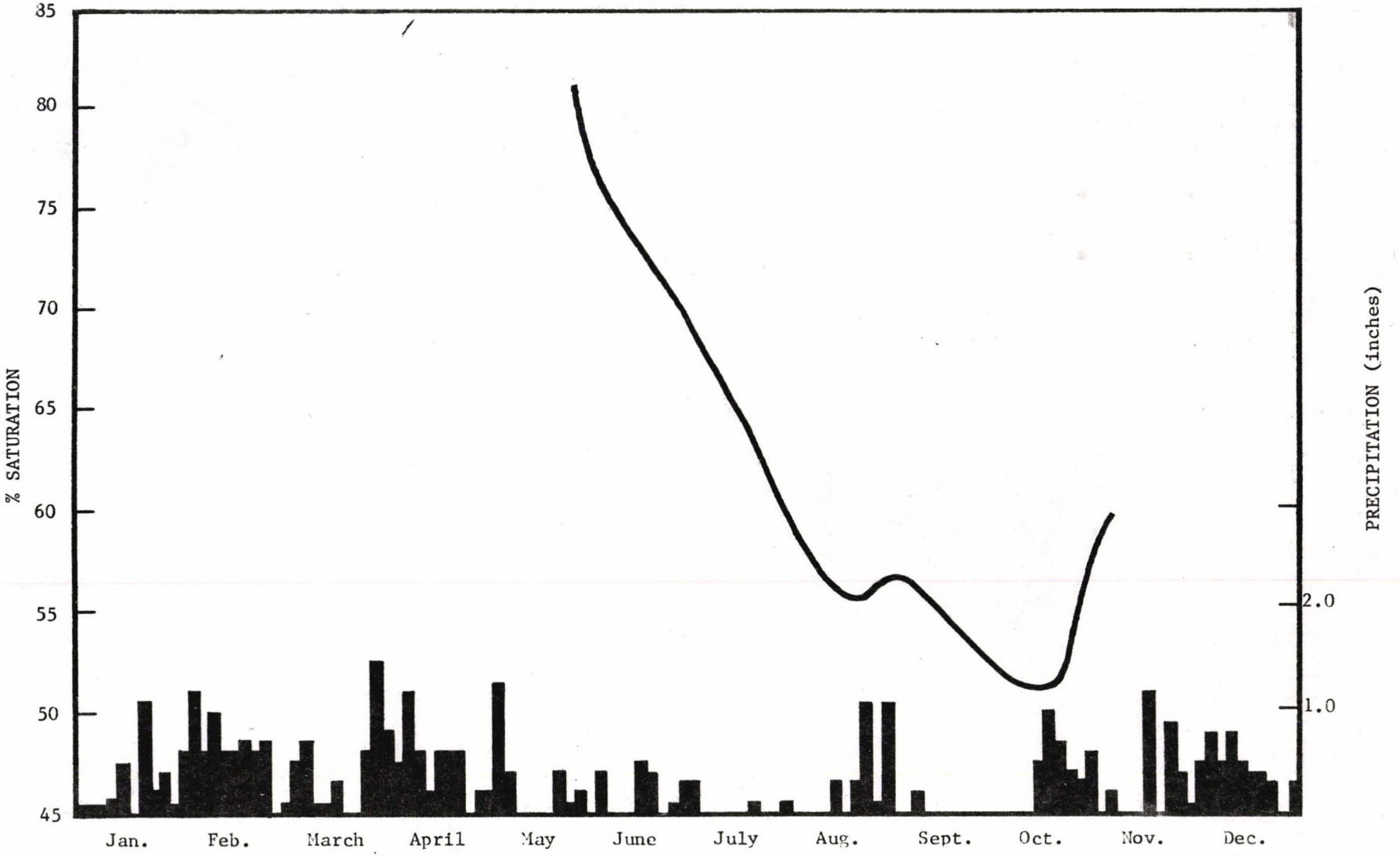

Figure 5. Average percent saturation of subgrade soil and precipitation, Horse Creek road 443.2, 1979.

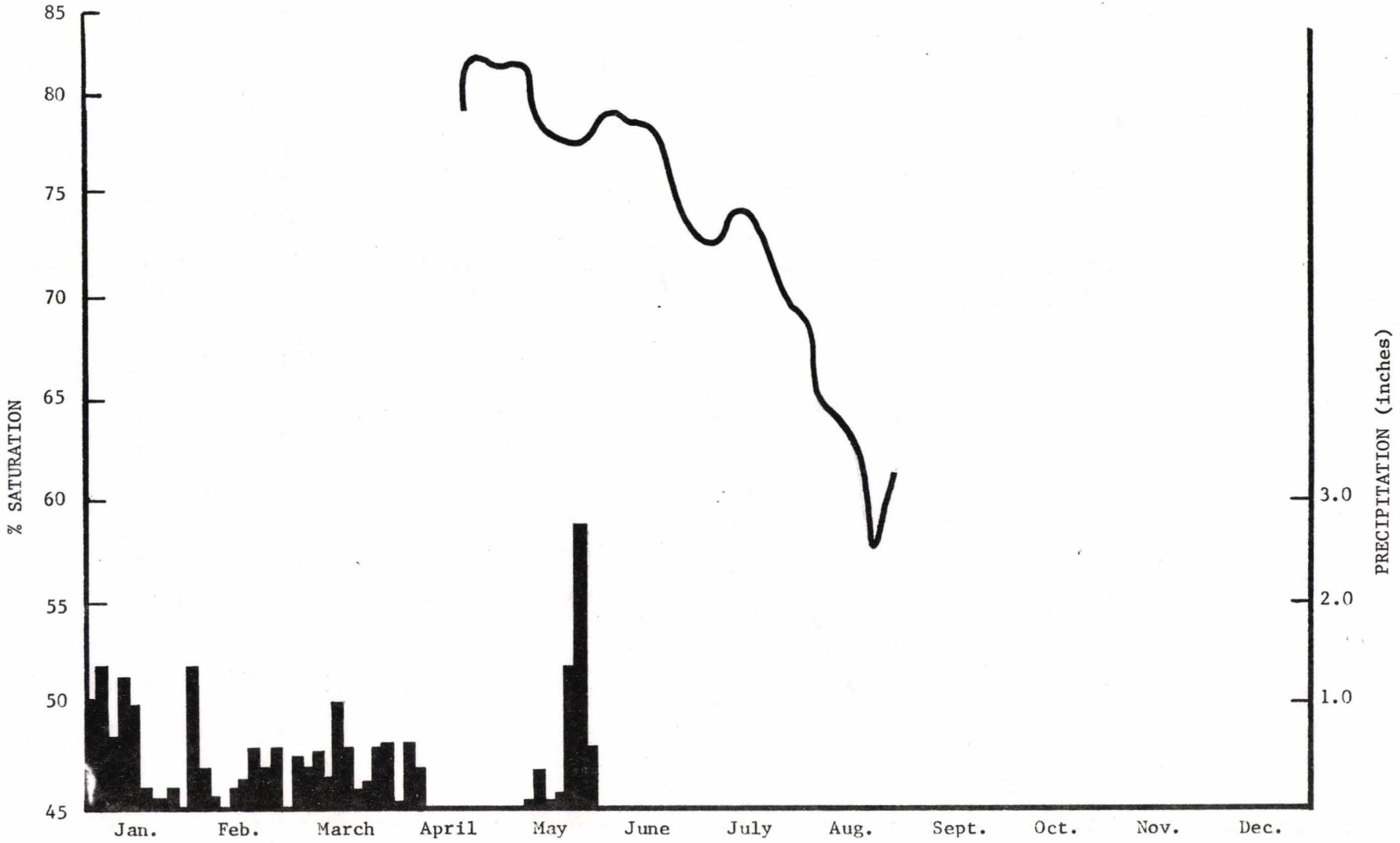

Figure 6. Average percent saturation of subgrade soil and precipitation, Horse Creek road 443.2, 1980.

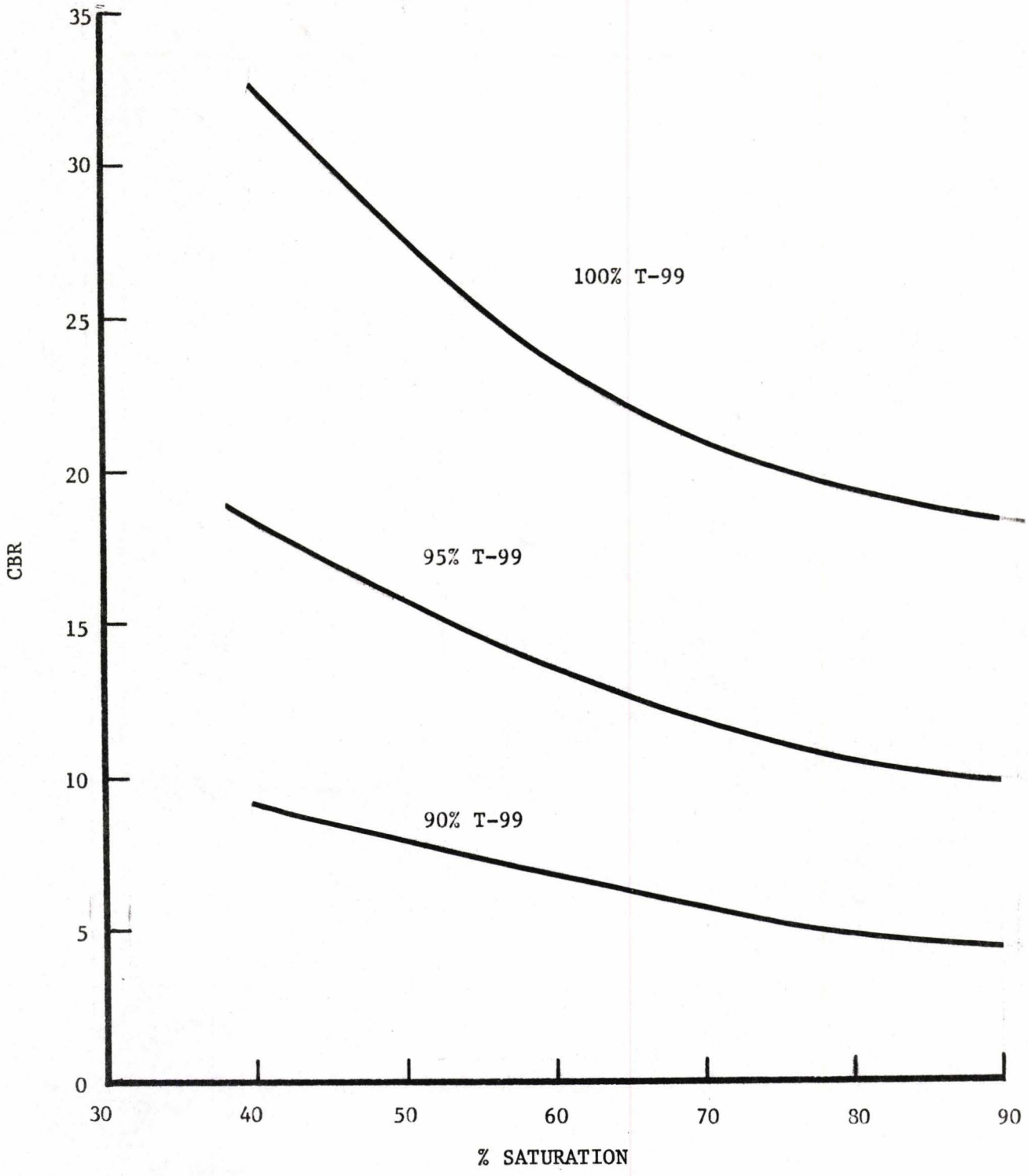

Figure 7. Average California Bearing Ratio versus percent saturation at various densities.

SECTION 13

ESTHETIC EVALUATION OF ALTERNATIVE ROAD DESIGN AND CONSTRUCTION PRACTICES

CONSTRUCTION PRACTICES AND COSTS: PERFORMANCE OF ALTERNATIVE DESIGN STANDARDS

ESTHETIC EVALUATION OF ALTERNATIVE ROAD DESIGN AND CONSTRUCTION PRACTICES

The specific objectives for this study are:

1. To establish the esthetic and visual qualities of the Horse Creek drainage before any harvesting or road building, as seen in far-, mid-, and near-views.

2. To measure the esthetic impacts of road building as seen in far- and mid-views.

3. To evaluate esthetic impacts of road building in near-view to determine:

   a. Differences between the two road standards.

   b. Differences in kinds of road construction.

   c. Differences in type and degree of revegetation following road construction.

   d. Impact of road building on focal points along the roadway.

Photographs showing the far-, mid-, and near-views of the Horse Creek watersheds in an undisturbed condition were taken in 1977. The esthetic and visual qualities of these watersheds were determined by a structured panel review of the photographs.

There were no photographs taken of the Horse Creek watersheds after road construction was completed. Photographs will be taken during the summer of 1981 of the roaded watershed as seen from far-, mid-, and near-views. Especially for the near-view photographs, it is desirable to have at least one year's regrowth of vegetation on the cut and fill slopes. Photographs taken in 1981 will be evaluated for their esthetic and scenic qualities by panel evaluation. This evaluation will be based on the Scenic Beauty Estimation Techniques (Daniel and Boster, 1976[1]).

The esthetic evaluations of the alternate road designs and the specific construction practices are scheduled to be completed and in report form by December, 1981.

[1]Daniel, Terry C., and Ron S. Boster. 1976. Measuring landscape esthetics: the Scenic Beauty Estimation Method. USDA For. Serv. Res. Pap. RM-167. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, CO.

CONSTRUCTION PRACTICES AND COSTS: PERFORMANCE OF ALTERNATIVE DESIGN STANDARDS

The specific objectives initially developed for this study were:

1. Monitor construction feasibility and cost of specific design features for which existing cost data are not adequate.

2. Determine total cost of alternative design standards, including costs of location, survey, design, construction, construction supervision, and specific design features.

3. Conduct trafficability and hauling cost studies for each standard.

4. Monitor maintenance costs and long-term performance of alternative standards.

Work to date has been directed toward the first two objectives, which are key elements in determining the cost effectiveness of alternative treatments and practices. Cost information is not in a format and condition to present at this time. Much of the information to meet objectives 1 and 2 needs yet to be determined from field notes on specific construction items. Information will be compiled from the contracting officer's diaries by representatives from the Nezperce National Forest engineering section and the Intermountain Station, Research Work Unit 3751. Additionally, cost data from a recent road study in the Silver Creeek Watershed will be extrapolated to the Horse Creek roads where possible.

Cost information will be developed and presented in the final report on road-related research on the site (tentatively scheduled for June 1982). Cost information will also be used in defining differences in cost effectiveness among alternative practices and treatments.

Present indications are that funding and resources will not be available to address the two latter objectives--trafficability, hauling costs, performance and maintenance.